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4th EDITION

Experimental Cookery

FROM THE CHEMICAL AND PHYSICAL STANDPOINT

BELLE LOWE
LATE PROFESSOR, FOODS AND NUTRITION
IOWA STATE COLLEGE

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To
P. Mabel Nelson

PREFACE

The large number of publications of research between the time the third edition of *Experimental Cookery* was published and the preparation of the manuscript for the fourth edition with an attempt to keep the book the same length brought about the necessity for considerable reorganization and rewriting to bring the material in the various chapters up-to-date. The chapter on food preservation has been omitted, and some of the material in this chapter has been incorporated in other chapters. A new chapter on Food Acceptability has been added. This chapter is written primarily for students starting problems in which sensory methods of evaluation for differences in food quality are used.

The aim in presenting the subject matter of the fourth edition is still threefold: to present the chemical and physical basis, particularly that of colloid chemistry, of food preparation in a form suitable for use as a textbook in college and as a reference book on cookery. The third aim is to introduce the student through the literature to those who have worked in this or related fields.

The author wishes to acknowledge the aid of Clara Gebhard Snyder in revising Chapter 12. Thanks are extended to Pauline Paul and Mary Morr for the reading of Chapter 2.

BELLE LOWE

Ames, Iowa
January, 1955

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CHAPTER
1

The Relation of Cookery to Colloid Chemistry

Thomas Graham's (11, 12) contributions constitute the first firm foundations of colloid chemistry. His most important results were published between 1861 and 1864. But it is only since the first publications of von Weimarn and of Ostwald in 1906 and 1907 that rapid development has been made in colloid chemistry. It is a very much shorter time that applications of colloid chemistry have been made to food preparation.

The material presented in this chapter is too brief to take the place of courses in colloid and biochemistry. At best it can only serve as an indication of the relationship between cookery and colloid chemistry. The topics covered are those common to practically all food products.

Colloid chemistry. Colloid chemistry deals with dispersed systems of a definite size since it is the size of particles in the colloidal range or zone that imparts the specific and characteristic properties which are not explained by the laws governing solid, liquid, or gaseous states of matter.

The colloidal range lies between that of crystalloidal systems and coarse suspensions. The lower limit for the size of colloidal particles is given as 1 $m\mu$, the upper limit as 0.1 μ (1 mm = 1000 μ; 1 μ = 1000 $m\mu$; 1 mm = 1,000,000 $m\mu$; 1 $m\mu$ = 10 A). However, there is no distinct line of demarcation between crystalloidal systems on the one hand and suspensions on the other. Instead there is a gradation in properties as well as in size. Particles approaching the limits of the size of one zone may show properties of two zones. For example, sugar has a high molecular weight and in cookery shows both crystalloidal and colloidal properties; in caramels that have not crystallized it is in a colloidal state. Even the particles within the colloidal range do not behave alike. The properties of colloidal particles approaching molecular dispersion are different from those of particles approaching molecular condensation and suspensions. The gluten particles of flour have colloidal dimensions. The gluten particles in cake and pastry flours (10) are more dispersed or of smaller size than those in bread flours. This is one reason for the different results obtained in cakes when bread flour is used instead of cake flour.

Bancroft (2) states that "adopting the very flexible definition that a phase is called colloidal when it is sufficiently finely divided, colloid chemistry is the chemistry of bubbles, drops, grains, filaments, and films, because in each of these cases at least one dimension of the phase is very small. This is not a truly scientific classification because a bubble has a film round it, and a film may be considered as made up of coalescing drops or grains."

Sols. The term sol was applied to liquid colloidal systems by Graham. Sols look like solutions, but differ from them in that the dispersed particles are of colloidal size. Some of the characteristic differences of true solutions, sols, and suspensions are listed in Table 1.

TABLE 1

CHARACTERISTIC DIFFERENCES OF

True solutions	Sols	Suspensions
In molecular subdivision	In colloidal subdivision	In mechanical subdivision
Particles are not visible with ultra-microscope	Refracted light of particles is visible with ultra-microscope	Particles visible with ordinary microscope or naked eye
Particles less than 1 mμ	Particles from 1 mμ to 0.1 μ	Particles greater than 0.1 μ
Formation of gels is not characteristic	Formation of gels is characteristic	Formation of gels is not characteristic
Transparent	Transparent	Generally opaque
Particles pass through parchment membranes	Particles or micelles pass through high-grade filter paper, but not parchment	Particles do not pass through high-grade filter paper
Intense kinetic movement	Less kinetic movement, more Brownian movement	Little movement
Systems show high osmotic pressure	Systems show low osmotic pressure	Systems show no measurable osmotic pressure

The dispersed phase. Terms used to distinguish the parts of a colloidal system are dispersed phase and dispersing medium; discontinuous phase and continuous phase; and micelles and intermicellar liquid.

State of micelles. The micelles may be solids, liquids, or gases, which in turn may be dispersed in solids, liquids, or gases, though the system gas in gas is not obtained in the colloidal state because gas particles are always found in molecular instead of colloidal size. If the systems are classified according to the micelles and intermicellar substance there may be solid in solid, liquid in solid, gas in solid, solid in a liquid, liquid in a liquid, gas in a liquid, solid in a gas, and liquid in a gas.

Sometimes the classification of colloidal systems is based on the dispersed phase only, and this is designated as a solid, a liquid, or a gas, according to the material dispersed.

Reproducing solutions and sols; hysteresis. A true solution can be reproduced if its (*a*) temperature, (*b*) pressure, and (*c*) concentration are known. To reproduce a sol such as a gold sol it is also necessary to know (*d*) the size of the dispersed particle. Gold sols of the same concentration may have different colors, depending upon the size of the micelles. However, when it comes to reproducing colloidal systems such as are found in an egg or a cake a fifth factor is necessary. Systems whose properties are dependent upon their previous history are said to show (*e*) hysteresis. It is the fourth and fifth factors that furnish us the explanation of why 18 cakes made by 18 girls from the same ingredients, at the same temperature and pressure, with the same concentration of these ingredients are different and why the nursery rhyme "Humpty-dumpty" is still as true today as when it was written. Returning to the cakes, not only slight differences in manipulation, *i.e.,* the amount of creaming and stirring but also the speed of the operator affects the results. A longer time allows more of the crystalloids, sugar, salt, and baking powder to dissolve as well as allowing greater absorption of liquids and other changes by the colloidal materials before the changes produced by baking are started.

Dialysis. Graham's distinction between colloids and crystalloids was based upon his diffusion experiments. Substances in solution that readily passed through parchment or other membranes (dialyzed) were designated as crystalloids; those that did not pass, as colloids. Dialysis is used for purification of colloids, *i.e.,* removing electrolytes.

Preparation of colloidal systems. For the methods of preparing colloidal systems the reader is referred to Gortner (9), Ostwald (22), Hauser and Lynn (13), or other textbooks on colloid chemistry. By means of the proper technic and method any substance can be brought into the colloidal state. For this either dispersion or condensation methods are used. Ostwald describes this as follows: "It may be accomplished either through the dispersion of nondispersed or coarsely dispersed substances, or through the condensation of molecularly dispersed systems. To these ends not only chemical but mechanical, electrical and other kinds of energy may be used."

Water passes from the molecular through the colloidal and into the suspension state in freezing. All crystalline substances pass through a colloidal zone in going into solution and in crystallizing from solution, for during crystallization the size of the particles increases, passing from molecular, through colloidal, to suspension dimensions. With a substance that crystallizes readily the trouble is not in getting it into colloidal dimensions but in stabilizing it, once these dimensions are reached.

Other properties of colloidal systems. For physical processes such as electrodialysis or filtration, and for oxidation-reduction and electrokinetic phenomena of colloidal systems the reader is referred to Freundlich (6, 7), and the previously mentioned or other textbooks on colloid chemistry.

Increasing and Lessening the Degree of Dispersion of Substances in Food Preparation

The methods and the ingredients used in food preparation often bring about increased or decreased dispersion. Although breakdown of the particle may occur, its state or subdivision, as indicated in Table 1, may not change. Sucrose is in molecular subdivision in solution. Hydrolysis of sucrose gives products (dextrose and levulose) still in molecular dispersion. Peptides and proteoses from protein hydrolysis are of colloidal dimensions. Starch, when acted upon by enzymes, may pass from the suspension into the colloidal (dextrins), and then into true solution (maltose and dextrose). Likewise stirring may prevent clumping although the particles may remain in suspension dispersion. It is suggested that the student list as many examples as possible under each of the methods of dispersion.

Heat. Increasing the temperature may bring about a greater or a lesser degree of dispersion. The heating of water increases its dispersion. The dispersion of fat globules in milk is increased by the application of heat to the milk, but when proteins are coagulated by heat the degree of dispersion is decreased.

Mechanical dispersion. The grinding of meat, nuts, and cereals is a mechanical means of dispersion. Beating and stirring also come under this means of bringing about dispersion. Stirring may prevent lumping or clumping, as in white sauce. Beating a curdled custard may reduce the size of the particles although neither the beating nor the processes mentioned above may reduce the size of the particles enough to change the systems from suspensions to colloidal systems. Homogenization of milk or cream is a mechanical means of increasing the dispersion of fat particles. Beating an egg white is a mechanical means of lessening the degree of dispersion, as it brings about partial coagulation of the egg white in the cell walls surrounding the air bubbles.

Dispersion by acids. The addition of or the development of acid in food preparation may bring about a greater or lesser degree of dispersion. The development of acid during the fermentation of bread dough induces dispersion of the gluten. The addition of acid to milk causes the casein to form a clot. If enough acid is added, the casein clot may be dispersed. The effect of acid upon many proteins often depends upon the resulting *p*H in relation to the isoelectric point of the protein. This will be considered later.

Dispersion by alkalies. The addition of alkalies may also tend to produce a greater or a lesser degree of dispersion. In quick breads and cakes the addition of soda in excess of the amount required to neutralize the acidity of the mixture may bring about increased dispersion of the gluten particles, which results in a definite grain or crumb.

The different methods of increasing or decreasing the degree of dispersion are applicable to all food products. Sometimes the effect may be modified by other factors. It is interesting to trace these through different classes of food products. If alkali is taken as an example, its effects on some foods may be cited. The alkalies, hydroxides of ammonia, sodium, and potassium or their basic salts are the ones considered. Calcium and magnesium salts may have different effects.

Sucrose is little affected by alkalies if they are not stronger than those ordinarily used in cookery. But when alkalies are added to the monosaccharid sugars they bring about decomposition. The properties of the decomposition products are different from those of the original sugar. The sweetness is partially or wholly lost depending on the extent of breakdown of the monosaccharid sugar. A brown color may also develop.

Vegetables and fruits are softened by the addition of alkalies during cooking, and they may become mushy and disintegrate. This is probably due to the greater dispersion of the cellulose and pectic substances. In dried legumes, alkalies may also increase the disintegration of some of the protein.

Milk is prevented from curdling or coagulating by the addition of alkali. Curdling is a lessened dispersion of the milk protein, casein. The addition of alkalies to eggs elevates the temperature for coagulation. Alkalies added to doughs cause a greater degree of dispersion of the gluten, which results in a dough that is runny and sticky to handle. In larger quantities the baking quality of the flour is partially destroyed. Alkalies added to gelatin tend to prevent its setting, and they may cause greater dispersion in emulsions.

Dispersion by enzymes. Enzymes may also cause an increased or lessened degree of dispersion in foods. The clotting of milk upon the addition of rennin is an example of lessened dispersion, but the proteinase enzyme in flour increases the dispersion of the gluten.

Definitions of Terms and Some Properties of Colloidal Systems

Each colloidal solution as well as each true solution has its own peculiar properties. These depend upon the nature of the particles in solution and the dispersing medium. But a large group of colloidal systems may have similar properties, and for convenience they are classified in a group or subdivision. The classification of colloidal systems into groups is not always satisfactory, for there is no distinct line of demarcation between the different subdivisions.

Reversible and irreversible colloids. If, after a colloidal solution is evaporated, a sol is reformed upon the addition of water, the colloid is classified as a reversible colloid. Gelatin and dried egg white are examples of this type of colloid. An irreversible colloid does not spontaneously form a sol with the addition of water, after water has been evaporated. Reversible and hydrophilic colloids are coextensive; irreversible and hydrophobic colloids belong to similar groups.

Hydrophilic and hydrophobic colloids. The terms lyophilic and lyophobic include all dispersing mediums, whereas hydrophilic and hydrophobic indicate that the dispersing medium is water. Hydrophilic means "water loving." Hydrophilic colloids have an affinity for or are soluble in water. Hydrophobic means "water hating," and hydrophobic substances or groups are characterized by low solubility in water. Two of the chief differences between hydrophilic and hydrophobic colloids are their degree of hydration or solvation and their reaction to electrolytes. The hydrophilic colloids are characterized by a high degree of hydration and by requiring a large quantity of an electrolyte to bring about flocculation or coagulation.

There is no distinct line at which the hydrophilic colloids leave off and the hydrophobic ones begin. Often slight modification may change a given colloid from one group to the other. For example, egg albumen, being extremely soluble in water, is a hydrophilic colloid. But when coagulated by heat it becomes insoluble in water and therefore hydrophobic. Denatured proteins are more or less hydrophobic. The hydrophilic colloids are not hydrated to the same extent; hence their stabilities vary. Typical hydrophilic colloids are gelatin, agar-agar, starch, pectin, and native proteins, whereas the metal sols belong to the hydrophobic colloids.

The term organophilic indicates that the substance is readily soluble in organic liquids.

Polar groups. In general, liquids and compounds may be divided into two classes: (*a*) those in which the molecules are symmetrical, and (*b*) those in which they are unsymmetrical. In an unsymmetrical molecule such as acetic acid, $CH_3 \cdot COOH$, the two ends do not behave alike at an interface. The CH_3 group is insoluble; the COOH group is so soluble that it pulls the CH_3 group into the water. The term polar group is applied to the COOH and similar groups to indicate that they behave differently from the CH_3 or non-polar group. A polar group in an organic compound confers upon it a degree of solubility in water. Some of the polar or hydrophilic groups are those containing oxygen, nitrogen, sulfur, iodine, bromine, phosphorus, and double and triple bonds, such as COOH, CHO, $C{=}O$, $C{\equiv}C$, OH, NH, NH_2, SH, $S{-}S$, SO_4H, PO_4H_2, and NCS. Some of the non-polar groups are the CH_3, the straight hydrocarbon chains, the branched hydrocarbon chains, and ring compounds. Many substances like the proteins and fatty acids contain both hydrophilic and hydrophobic groups; *i.e.,* they are neither completely hydrophilic nor completely hydrophobic. The efficiency of emulsifiers and stabilizers in foods depends upon a balance between polar and non-polar groups.

Isoelectric point. The prefix "iso" means equal or the same. Hence the isoelectric point is that *p*H of a protein solution at which the positive and negative charges are the same. It is the electrical null or neutral point. At this point the protein does not migrate to either the anode or the cathode in electrophoresis or cataphoresis experiments. The term isoionic (*pI*) is used, as its name suggests, to designate the *p*H of the solution in which the ions (H and OH) are equally combined with or dissociated from the protein. It is identical with the isoelectric point provided that the protein reacts with no other ions. Above the isoelectric point the protein particle is negatively charged and acts as an anion. Below the isoelectric point it is positively charged and functions as a cation.

The isoelectric point of most proteins lies between *p*H 4.5 and 7. Proteins with isoelectric points in the low *p*H range are designated as acid proteins; those in a high *p*H range as basic proteins. The former have a high percentage of the acidic amino acids, the latter of the basic amino acids. Pepsin, isoelectric point reported from *p*H 2.5 to 3, has a high content of the amino acids tyrosine, aspartic, and glutamic acids. The protamines, isoelectric points reported from *p*H 9.7 to 12.4, have a very high content of the basic amino acids, and of arginine in particular.

Certain of the properties of proteins are at a minimum at the isoelectric point. Hence the isoelectric point is often determined by locating some of these minima instead of using the direct electrophoresis method. Other characteristics are at a maximum at the isoelectric point. Clayton (5) lists those at a maximum as analytical purity, turbidity, and surface-tension lowering; those at a minimum as viscosity, optical rotation, stability in solution, ash content, electrical conductance, osmotic pressure, and membrane potential. The swelling of gelatin is also at a minimum at the isoelectric point.

The charge on colloidal particles. The origin of the charge on colloidal particles is still disputed though it is agreed that the micelles possess either a negative or a positive charge. The charge may come from ionization of the micelle or from adsorbed ions. Another possibility is that it may originate by electrification by contact with the dispersion medium in the same manner that a glass rod becomes charged when rubbed with fur. Kruyt (15) emphasizes that one of the most important properties of colloidal particles is the fact that they are generally electrically charged with respect to their surroundings. There is a close connection between the electrical properties of a sol and added electrolytes.

Freundlich (6, 7) uses the term electrokinetic phenomena to designate certain electrical properties of colloidal systems. These electrokinetic phenomena (6) are closely associated with the physical properties of interfacial tension, adsorption, colloidal stability, mutual precipitation, and flocculation.

The electric double layer. The theories (9, 15) that have been advanced to explain electrokinetic phenomena are based upon the double-layer theory of Helmholtz. Very briefly this theory is that the micelle is surrounded by a double layer of ions, the inner layer, which may be negative or positive, being closely adsorbed by the micelle, and the outer layer, consisting of ions of opposite charge from those of the inner layer, lying close to the inner layer of ions and the micelles in the intermicellar liquid. As the colloid passes through its isoelectric point the charge of each double layer is reversed.

Effect of electrolytes upon hydrophobic colloids. Since the hydrophobic sol is not hydrated its stabilization depends only upon its electric charge. The micelle is rendered isoelectric and flocculated by the ion (*a*) of the electrolyte having the opposite charge from that of the micelle, *i.e.,* the cation, if the micelle is negatively charged, and the anion, if positively charged. If more of the electrolyte is added than required for precipitation of the micelles a sol may reform which possesses an electric charge opposite to that of the initial sol. In general the amount (*b*) of the salt required to produce flocculation varies with the valence of the ions bringing about the flocculation. Monovalent ions are less effective than divalent ones, and in turn divalent ions are not nearly as powerful as trivalent ions. The effect of valence and of the addition of electrolytes is illustrated in Experiment 41D when distilled water is substituted for milk in custard. Heating renders the egg hydrophobic, but added salts are necessary to bring about "setting" of the custard. The amount of salt required also varies with the valence of the cation. There are some exceptions to the effect of valence, in that some monovalent ions have greater flocculating power than polyvalent ones. The concentration of the colloid (*c*) also affects the amount of electrolyte required. If the electrolyte is added in small portions (*d*) more is required than if it is added all at once. Presumably this might mean that the addition of salt to cream of tomato soup in small portions would be less likely to cause it to curdle (flocculate) than if all the salt is added in one portion. Probably electrolytes have some role in the flocculation of milk in Experiment 4. If the large quantity of milk in this caramel recipe is not added in small portions it nearly always curdles. A definite time (*e*) may be required before flocculation occurs.

Casein of milk is a good example of a colloid that is little hydrated and is stabilized by an electric charge. It can remain in the sol form when negatively or positively charged. However, when the charge is neutralized the casein flocculates. The charge is neutralized in natural souring, and when it reaches the isoelectric point of the protein the casein clots.

Effect of electrolytes upon hydrophilic colloids. Hydrophilic colloids can be reversibly precipitated by high concentrations of ammonium sulfate and magnesium sulfate. The reason for this "salting-out" effect is that both stabilizing factors are removed, *i.e.,* the hydration and electrical charge. Dehydration of the hydrophilic colloid may be brought about by different means, such as heating, the use of tannin, and alcohol. The colloid is then sensitive to the effect of small amounts of electrolytes. If small quantities (15) of electrolytes are added to a starch or agar-agar sol the electrical charge is removed, but the particles do not precipitate. If alcohol is added to the above starch or agar-agar sol, flocculation occurs. It is immaterial in which order the two stability factors are removed. The removal of one has no evident effect, but the removal of both factors causes coagulation.

Protective and denaturing colloids. A substance in the colloidal state that prevents the coagulation of micelles is called a protective colloid. Lyophilic systems (13) are particularly efficient in protecting lyophobic systems. The ratio of the protective colloid to that being protected is important. If too little is used it may sensitize instead of protect. The colloid bringing about sensitization is known as a denaturing colloid.

Gels. There is no distinct line of separation between a sol and a gel. In fact some sols become gels by increasing the concentration of the micelles. A typical sol is fluid; a typical gel has a certain amount of rigidity. The term "gel" is inclusive, covering all types of gels. This includes a variety of substances, such as wool and wood, in addition to those used in food preparation. The term "jelly" is used by some investigators for gels which appear homogeneous and contain a high percentage of water; by others it is applied to heat-reversible gels such as gelatin. Fruit jellies and gelatin desserts are typical gels. They resist deformation or can be molded, assuming the shape of the container in which they gel.

Gels are unique in that the dispersion medium is still liquid but is held in the gel state by the micelles forming a definite structure. Crystalloids soluble in water can diffuse through gels nearly as rapidly as through water. Particles of colloidal size do not diffuse through gels. This can be shown easily by using dyes of different-sized particles and noting the rate of diffusion.

A contraction occurs in gel formation. The volume of the dry micelles plus that of the dispersion medium is greater than after the two are combined. This indicates (9) a packing of the molecules of the dispersion medium surrounding the micelles.

The theories advanced to explain the mechanism of gel structure are many and varied. But, whatever the mechanism by which the water is held, the amount of water so held is often relatively enormous. A concentration of 1% agar-agar gives a stiff gel, and 0.75% of pectin gives a good fruit jelly. As the concentration of the pectin or agar-agar is increased the stiffness of the jelly is increased.

Gels are important in food preparation. The intracellular proteins of meat are in the gel state. Additional examples are the gels formed by eggs, starch, and flour proteins in soufflés, puddings, and batter and dough products.

Swelling of gels. Katz (14) in his review of "the laws of swelling" states that a solid swells when it takes up a liquid, and at the same time (*a*) it does not lose its apparent (microscopic) homogeneity; (*b*) its dimensions are enlarged; (*c*) its cohesion is diminished; and (*d*) instead of being hard and brittle it becomes soft and flexible. The ability of the proteins and starches to imbibe water is very great.

The extent of swelling is influenced by various factors, among them the previous history. For example, Lloyd and Shore (19) state that, after once drying out, the swelling capacity of the micelles is reduced: 1000 grams of a 10% gelatin jelly will attain a weight of only 600 grams when allowed to swell until equilibrium is reached.

Effect of added substances upon swelling of gels. The addition of such substances as acids, alkalies, mineral salts, and sugar may increase or inhibit the degree of swelling. Many such combinations are made in cookery. Lemon juice and vinegar may be added for flavor. Soda, salt, and baking powder may be added to foods. Different proportions of mineral salts are found in foods, and the proportion may vary in the same food owing to many causes. In general, the addition of acids or alkalies increases the swelling of colloidal gels. With acids, this usually continues until a maximum is reached at *p*H 3.0 to 2.5, when imbibition is decreased with greater acidity. With alkalies the maximum swelling is about *p*H 10.5, though gluten gels are likely to disintegrate when they become as alkaline as this. Sometimes the addition of acids or alkalies lessens hydration. This depends upon the *p*H of the substance when the acid or alkali is added. In general, salts lessen the degree of swelling even in the presence of acids or alkalies.

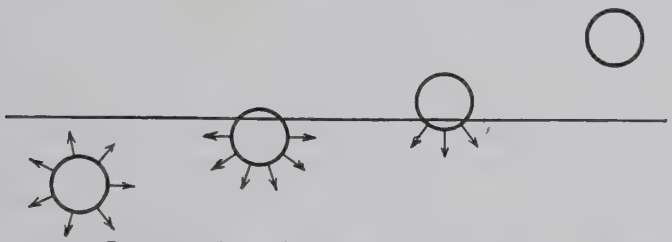
Syneresis. After gels are allowed to stand protected against evaporation for a number of hours there is a tendency for the gel to separate into two phases. A liquid may squeeze out of the gel. A typical example is the separation of the whey from the curd in clabbered milk. It is also noticed in some jellies, cranberry jelly in particular. In some food gels this separation into a more solid and a more liquid part may take a long time, in others a shorter time.

Boundary Phenomena

Because of the size of micelles, surface phenomena assume an important place in colloidal reactions. In fact it is only in colloid chemistry that the surface energy becomes more important than the internal energy. Surface tension, the formation of foams, interfacial tension, adsorption, formation of surface skins, orientation of molecules, cohesion, and adhesion all have application in food preparation. Different authorities use a different terminology to designate the chemical and physicochemical processes taking place at the interface between two phases. Kruyt (15) calls them boundary phenomena; Freundlich (7) designates them as capillary chemistry; and other authorities use other terms.

Freundlich states, "The subject of capillary chemistry may be divided into natural subdivisions, according to the nature of the interfaces which separate the various possible pairs of phases. We can distinguish the following interfaces: liquid/gaseous, liquid/liquid, solid/gaseous, solid/liquid, solid/solid. Because of the complete rigidity of the interface between two solids, the section relating to this pair drops out."

Surface tension. Arbitrarily, surface tension refers to the tension of a liquid/gas interface. Liquids like gases possess kinetic energy, but unlike gases they have a surface or a boundary layer. This boundary layer gives a liquid certain properties that gases do not have. Surface tension is the result of the inherent property of a fluid to tend to form a minimum surface under all conditions. The minimum surface for a given volume is in the form of a sphere; hence, when free to do so, liquids assume a spherical shape. Small drops of water falling on a dusty surface or a waxy leaf tend to form in drops. Large drops are flattened by gravity. When drops of water fall on a surface like clean glass, they spread and wetting occurs. The forces acting between the clean glass and the liquid prevent the liquid from assuming a spherical shape.



Courtesy of R. A. Gortner and John Wiley & Sons

FIG. 1. A diagrammatic representation of attraction of liquid molecules for other molecules in the liquid.

All molecules have attraction and repulsion for other molecules. For a liquid molecule within the body of a liquid these forces are balanced on all sides. But the surface film is in a state of tension because of the unbalanced attractions of the molecules at the surface. The force attracting liquid molecules to gas molecules is very much weaker than their attraction for other liquid molecules. The attraction of a liquid molecule in the surface for other liquid molecules is downwards and sideways. See Fig. 1. Thus the molecules in the surface layer become more concentrated than in the interior of a liquid and are oriented or packed tighter in a definite or orderly manner. Although this surface layer is composed of molecules held in an oriented position by attractive forces, it has some properties characteristic of a membrane. It cannot be punctured like a rubber balloon, but a water surface can float a needle or a razor blade. Surface tension (6, 15) is defined as the amount of work necessary to produce a new surface of unit area at a constant temperature. To enlarge the surface, work needs to be expended. The amount of work required is greater the higher the surface tension of the liquid and the more the area is to be increased, or the amount of work is equal to the surface tension times this area. The amount of work expended to enlarge a surface multiplied by the area increased is known as the free surface energy. Free surface energy tends to be a minimum quantity, since the area of the surface also tends to be a minimum as a result of surface tension. The free surface energy is decreased (*a*) by reducing the surface area or (*b*) by reducing the surface tension. Hence, small drops of liquid will unite with large drops if they are within the same space so that they are connected by their vapor, thus reducing the surface area.

Surface tension is measured in dynes per centimeter. The surface tension of water, which is high, at 18°C is 73; that of ethyl alcohol, methyl alcohol, and chloroform at 20°C is 21.7, 23.0, and 26.7, respectively. The surface tension of mercury at 15°C is 436.

Surface tension decreases with increase in temperature, becoming zero at the critical temperature.

The surface tension of solutions. When a substance is dissolved in a pure liquid the surface tension of the solution may not be changed, it may be raised, or it may be lowered. The substances that scarcely change the surface tension or elevate it slightly include the aqueous solutions of most electrolytes and some organic compounds. Sugar increases the surface tension of water. These substances (7) are called capillary-inactive or surface-inactive. The group of substances that lower surface tension includes in aqueous solutions many organic compounds such as aldehydes, fatty acids, fats, acetone, amines, alcohols, tannins, saponins, and proteins. This group of substances (7) is called capillary-active or surface-active. If a substance lowers or increases the surface tension, the effect is always increased with its concentration. Surface tension can be lowered tremendously, but it can be raised to only a slight extent. If a substance lowers the surface tension its concentration is greater in the boundary layer than in the bulk of the liquid; and, conversely, if the substance raises the surface tension the concentration is less in the boundary layer.

Substances like the fatty acids, formic, acetic, propionic, and butyric, that belong to a homologous series, show an increased lowering of the surface tension as the series is ascended, if they are kept at the same concentration. This regularity of increase with such a series is known as Traube's rule.

Interfacial tensions of liquids/liquids. Interfacial tension refers to the tension at liquid/liquid or liquid/solid interfaces. When two nonmiscible liquids are poured together, one liquid forms a layer on top of the other, thus making a liquid/liquid boundary. The less the solubility of the two liquids in each other, the greater their interfacial tensions; but most liquids are not completely insoluble in each other. Just as a substance may concentrate at a liquid/gaseous interface, so likewise those substances which decrease interfacial tension tend to concentrate at a liquid/liquid or a liquid/solid interface. With the addition of a third substance soluble in water, Traube's rule holds, but if it is more soluble in the second liquid then the lowering of the interfacial tension is small and Traube's rule scarcely applies.

Adsorption. Adsorption has been defined as the concentration of a substance at an interface. As has been noted, free surface energy tends to a minimum and substances that lower the surface tension concentrate in the surface. One means of decreasing the free surface energy is to lower the surface tension. Positive adsorption is defined as the concentration of the solute in the interfacial layer; negative adsorption, as its concentration in the interior, or, vice versa, the concentration of the solvent in the interfacial layer. The amount adsorbed depends on the concentration of the material being adsorbed and the extent of the surface at which it can be adsorbed.

The importance of surface reactions cannot be overemphasized in food preparation. They occur in emulsions, foams, and throughout the interface of mixtures when such substances as fat, sugar, salt, baking powder, flour, and egg are combined.

Bancroft (2) states that peptization is always due to adsorption. Since peptization occurs frequently in food preparation, additional mention should be made of it here in connection with adsorption. Theoretically (2) there are three possibilities when adsorption occurs at a surface. (*a*) If an adsorbed film has a low surface tension on the water side and a high one on the other side, it will tend to scrunch up and to peptize the solid as internal phase. (*b*) If the reverse is true, the solid will tend to form the external phase. (*c*) If the two surface tensions are equal, neither will prevail. Many instances of peptization might be mentioned. There is the prevention of coagulation by heat of peptizing action of sugar on egg protein. There is the peptizing action of soda on flour proteins with increasing tenderness of the product. This occurs in the chocolate cake known as devil's food when excess soda is used.

The interfacial tension of solids/liquids. Adsorption is very pronounced at the interface between these two phases. Just as small drops of a liquid will unite through their vapor to form larger drops, thus reducing the free surface energy and their surface area, so small crystals in a supersaturated solution will unite to form larger crystals. Small crystals have a greater solubility than large crystals. They also have a greater surface area per unit mass, and thus a greater surface energy. Since surface energy tends to a minimum, equilibrium can be reached only by establishment of larger crystals in the solution. The growth of crystals in fondant and similar candies during storage is discussed later.

Formation of foams. Adsorption at liquid/gaseous interfaces. A foam is a dispersed gaseous phase, the dispersing medium often being a liquid. The solutions of substances that lower surface tension tend to froth, particularly if the liquid is not too volatile or too mobile so that the foam collapses readily. Freundlich states that the formation of a foam is a complicated phenomenon. "Whilst in most other colloidal structures the particles of the disperse phase are of colloidal minuteness, this is by no means essential or even usual, in the case of foams. On the other hand the dispersion medium is often of colloidal fineness, that is, the gas bubbles are separated from one another by liquid films, having a thickness of only a few mμ. Hence in a foam the surface of a liquid has been enormously extended, which is in opposition to the tendency of surface tension to make the surface a minimum. For this reason a liquid must fulfil a number of special conditions. In the first place the surface tension of the liquid must be small, for otherwise its tendency to reduce the surface would be too powerful." A second condition for the production of stable foams is that the vapor pressure shall be small, for substances with high vapor pressure evaporate rapidly. The surface films must not coalesce readily. These conditions are fulfilled by aqueous solutions of capillary-active substances, and especially by sols of many colloids, like soaps, saponins, tannins, and proteins. Freundlich states that in protein solutions a third influence plays a part, for they have the property of forming thin "pellicles" or surface skins on the boundary layer, which tend to prevent evaporation. At least part of these pellicles are the layers of adsorbed, surface-denatured proteins. Adam (1) states that a more important factor than low surface tension for the stability of a foam is that the solution have a surface tension which is easily and quickly variable.

Since the substance that lowers surface tension of the liquid is found in greater concentration in the foam, if the foam is continually removed as it is formed, the greater portion of the protein or other substance is removed. This is applied in the following and similar ways. In making sorghum molasses, in order to have a delicate-flavored product, one must have "a good boil" and remove the scum forming on the surface. In this way, tannins, which would increase the bitterness of the sorghum, proteins, and other substances, are removed.

Rahn (23) has shown analytically the results of the application of "the law of Gibbs and Thomson which states that substances which cause a depression of surface tension will accumulate in the surface. In a gelatin solution, there is more gelatin in the very surface layer than in the center of the solution." In a milk foam the concentration of protein is greater in the foam than in the solution. The results are shown in Table 2.

Rahn states that "If protein is concentrated on the surface it has a tendency to become solid, but all proteins do not behave alike. Some solidify rapidly, others slowly, and some do not solidify at all. Quite often, this solidification is irreversible, and the protein, when put back into the solution, will not dissolve again." When milk foams, solid walls form around the air bubbles and, when the foam settles, these walls of protein can be seen with the aid of a microscope.

Wetting agents. Bartell (3) gives a good description of wetting agents and their mode of action. Wetting agents are those which lower

TABLE 2

COMPOSITION OF SKIMMED MILK AND ITS FOAM (*Rahn*)

Constituent of the milk	Average of 9 experiments with intensely foaming skimmed milk		Average of 6 experiments with slightly foaming skimmed milk	
	Liquid part %	Foam %	Liquid %	Foam %
Protein	3.09	3.51	3.01	3.24
Fat and lactose	4.85	4.73	4.92	4.92
Ash	0.75	0.78	0.74	0.76
Total solids	8.69	9.02	8.67	8.92
Protein increase in the foam		13.6		7.6

interfacial tension and are known as cleaning agents, dispersing agents, detergents, and emulsifiers. Wetting agents are not equally effective at all surfaces, *i.e.,* liquid/air, liquid/liquid, or liquid/solid.

A wetting agent possesses a polar or hydrophilic group and a non-polar or hydrophobic (organophilic) group. For nearly all purposes (3) the most effective agents are those whose hydrophilic groups exhibit a strong affinity or solubility for the water whereas the hydrophobic groups have a strong affinity for the organic liquid or organophilic phase. "If these two tendencies are not well balanced the efficiency of the agent may be lost through the fact that the end with the stronger character will tend to carry the molecule too completely into that phase for which the solubility tendency is the greater." A wetting agent with both strong hydrophilic and hydrophobic groups is oriented at the interface and lowers the surface tension (and free energy) at the interface. "The efficacy of the agent is determined by the extent of the energy change at the interface."

Orientation of molecules. Monolayers. The molecules at an interface do not lie at random but are oriented or arranged in an orderly manner. The arrangement assumed depends upon the molecule, whether it is symmetrical or asymmetrical, and the nature of the interface. At an air/water interface the organophilic groups are oriented towards the air, the hydrophilic groups towards the water, for water has pronounced polar characteristics. "Like attracts like" is a rule that all students of organic chemistry have learned.

Langmuir (16), Gorter (8), and Langmuir and Schaefer (17) have reported work with protein monolayers. Many proteins, such as ovalbumin and pepsin, may be spread on a cleaned water surface to form insoluble monomolecular films. Spreading into monomolecular films is dependent upon the molecule having hydrophobic and hydrophilic groups. The spreading of protein monolayers (8) is influenced by several factors: the technic used, the *p*H of the spreading solution (spreading being almost instantaneous at the isoelectric point, but requiring more and more time on each side of this point until very acid and very alkaline solutions are reached), the type of protein, and the electrolytes present (bivalent and trivalent ions are more active in smaller concentrations than the monovalent ions). Many properties (8, 16, 17) of these monolayers have been measured. Langmuir (16) states, "The most remarkable property of protein monolayers on water is their extraordinary insolubility." Through surface denaturation the hydrophobic groups of the protein (which in the native protein are in the interior of the molecule) come to the surface. One of the interesting properties of these monolayers is the pattern (which seem to be characteristic for each protein) formed with "indicator oil."

Bound and Free Water

Water is present in starches and proteins, hence in meat, eggs, custards, gels, baked products, etc., in two forms: (*a*) that forming part of the molecule; and (*b*) that which contains the dissolved salts, proteins, sugar, etc. The first form is usually designated as "bound" water, although it is sometimes referred to as water of hydration (24) in proteins.

Bound water is so closely associated with the molecule with which it is combined that it no longer has the characteristics of ordinary water. Some of these changed characteristics are: (*a*) it no longer acts as a solvent for solutes such as sugar; (*b*) it has no appreciable vapor pressure; (*c*) it cannot be frozen; (*d*) it cannot be pressed from the tissue; and (*e*) it is very dense.

Lloyd and Moran (18) state that it appears that the bound water of gelatin is unfrozen above −105°C. Pressures (18) between 8000 and 38,000 pounds per square inch remove a very small fraction of the bound water, but with higher pressures more water is removed. The data (18) show that 1 gram of dry gelatin carries about 0.5 gram of bound water. This is equivalent to 1 molecule of gelatin (mol. wt., 34,500) binding 960 molecules of water, which is very close to the possible number that can be held by the "co-ordinating centers." Moran (20) finds that apparently all the free water of muscle is frozen at −37.5°C. He states that "in the presence of salts or other dissolved substances the water relations of a protein may be altered very considerably."

There is some connection between bound and free water whereby at least a portion of the bound water may become free, and vice versa.

Fluidity, Viscosity, and Plasticity of Colloidal Systems

Fluidity and viscosity. Bingham (4) uses the term fluidity to express the opposite of viscosity. Viscosity is one of the important properties of colloidal systems. As a general rule, the lyophobic colloids show a viscosity but little greater than that of the dispersion medium, the viscosity increasing only slightly with increasing concentration of the micelles. But the lyophilic colloids may show very high viscosities or even plasticity with very low concentrations of the micelles.

Bingham states that "a mixture of liquids may have an indefinite number of fluidities dependent upon the method of mixing, in other words, upon the structure of the liquid." He also states that colloidal solutions show differences in fluidity due to differences in structure. The structure or crumb of baked products may show differences, even though made from the same materials and the same weights of these materials, because the viscosities of the batters varied owing to different methods of mixing.

Some substances flow readily; others resist flow; and some must have weight applied to start flow. When a substance tends to resist a shearing force it may exhibit a flow that is characterized as viscous, turbulent, or plastic. If the substance entirely regains its original shape when the shearing stress is removed, it shows perfect elasticity. If the original shape is not entirely regained and the substance is deformed to an extent directly proportional to the shearing force, then the substance is said to show viscosity.

A pure liquid at a given temperature and pressure has a definite fluidity. The viscosity of water is approximately six times as great at 0° as at 100°C. The viscosity of sols usually decreases with an increase in temperature, part of this decrease being due to the effect of temperature upon the intermicellar liquid. Thus gelatin and agar-agar form sols with rather low viscosity at high temperatures when compared to the viscous liquid or plastic gels they form at low temperatures. Starch usually forms a suspension at low temperatures, and its decided increase in viscosity or plasticity comes with rapid hydration at the gelatinization point. Electrolytes added to lyophilic systems, even in traces, often cause great changes in the viscosity of the sol.

The factors affecting the viscosity of hydrophilic systems. Ostwald (22) lists ten factors causing variation in viscosity of hydrophilic systems: (*a*) concentration, (*b*) temperature, (*c*) degree of dispersion, (*d*) solvation, (*e*) electrical charge, (*f*) previous thermal treatment, (*g*) previous mechanical treatment, (*h*) the presence or absence of other lyophilic colloids, (*i*) the age of the lyophilic sol, (*j*) the presence of both electrolytes and non-electrolytes.

Viscosity is closely related to the consistency of the finished product in food preparation. So close is this relation in many cases that the ten factors listed by Ostwald may nearly be taken as ten commandments of food preparation. Thus the consistency of a custard is influenced by the concentration of egg or the protein micelles; the temperature to which it is cooked; the degree of dispersion of the micelles, which is influenced by the reaction and other factors; the degree of hydration, which is influenced by reaction, the kind and concentration of salts present, etc.; the beating of the egg; the use of milk or water; how long the custard has aged in addition to the age of the eggs and milk when used; the kinds and concentration of salts in the egg and milk as well as the addition of sodium chloride and the non-electrolyte sugar.

Since the line of demarcation between sols and gels is not a definite one, fruit jellies, gelatin, milk, cream, as well as egg dishes, may be included in the group of foods in which the consistency of the finished product is related to viscosity. But this does not end the application, for the structure or type of product in baked goods is closely related to the viscosity of the batter or dough, which in turn is influenced by all these factors. Of course, these factors or nearly the same ones affect other properties as well as viscosity of food materials. Thus the extensibility of gluten, the heat coagulation of proteins, etc., are influenced by many or all of these factors.

Plasticity. Bingham defines plasticity as "a property of solids in virtue of which they hold their shape permanently under the action of small shearing stresses but they are readily deformed, worked or molded, under somewhat larger stresses. Plasticity is thus a complex property, made up of two independent factors, which we must evaluate separately." Modeling clay is plastic. Plasticity is an important property of fats used for cakes, biscuits, and pastry. A plastic fat has a consistency such that it will form a thin sheet or layer in a batter or it will retain air bubbles when "creamed."

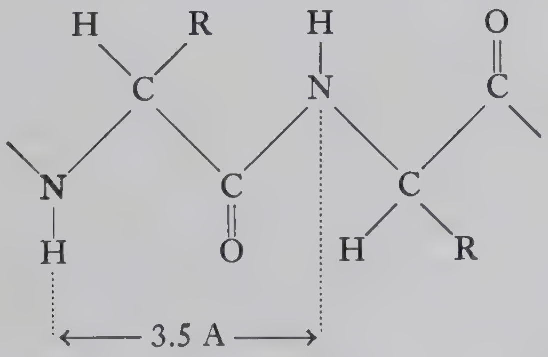
Protein Structure

It has been known for a long time that proteins are made up of amino acids connected through the amino and carboxyl groups, this structure being designated as a polypeptide chain, and that they have a very high molecular weight. These amino acids may be split apart by hydrolysis. However, for reactions occurring in food preparation or physical and chemical tests, the polypeptide chains often remain intact. Thus when an egg white is cooked some of the characteristics of its albumin are changed, but the polypeptide chain remains intact and it still has the same amino acids. Since the polypeptide chain is common to all proteins and many of the amino acids are common to all proteins, the structural configuration must have a role in determining differences and similarities in many proteins. As would be expected these differences and similarities of proteins are of extreme interest to the research worker. In turn, the findings of the investigators of protein research are of interest to those who apply the chemical and physical findings in practical fields.

Neurath (40) states that the proteins built from amino acids must not have any unreasonable deviation from the accepted bond angles and interatomic distances, and the distribution and orientation of the amino acid residues must be such as to allow sufficient room for their accommodation. Many other things must also be considered. Among these the following are mentioned: (*a*) whether the amino acids are linked in *cis*- or *trans*-positions in the —N—C—C—N— links of the polypeptide chain; (*b*) the type of interlinks or bonds holding the chains together; (*c*) whether the polypeptide chain is folded or coiled in the globular proteins and the supercontracted fibrous proteins and the type of intra- and inter-bonds that holds it in this position. (*d*) Are these intrabonds easily broken for a stretched configuration under stress or when the protein is denatured? (*e*) What type of contraction of the configuration accounts for the shrinkage or contraction of collagen during the cooking of meat or when collagen is heated in water? (*f*) What type of configuration allows gelatin to form a gel at low temperatures and a sol at higher ones? Many other questions could be included but these are sufficient to indicate that the reactions and behavior of proteins are of interest in food preparation. To emphasize one dramatic point, how does a toxic protein differ from a non-toxic one? The amino acid (29) content of the *Clostridium botulinum* type A toxin has been determined. This amino acid analysis gave no explanation for the extreme toxicity of the protein or how the toxin is rendered non-toxic by heating to a sufficiently high temperature.

The use of x-ray, infra-red, chemical, and electron microscope as well as other methods has added much to the knowledge of proteins structure. However, much remains to be determined.

The polypeptide chain. The linking of the amino acid through the amino and carboxyl groups forms a repeating unit, N—C—C, throughout the long protein molecule. This repeating unit forms the backbone of the molecule and is usually represented as having either a zigzag or a spiral direction. At least for some proteins and in some configurations, the measurement of this unit is 3.5 A. It may be represented as follows:

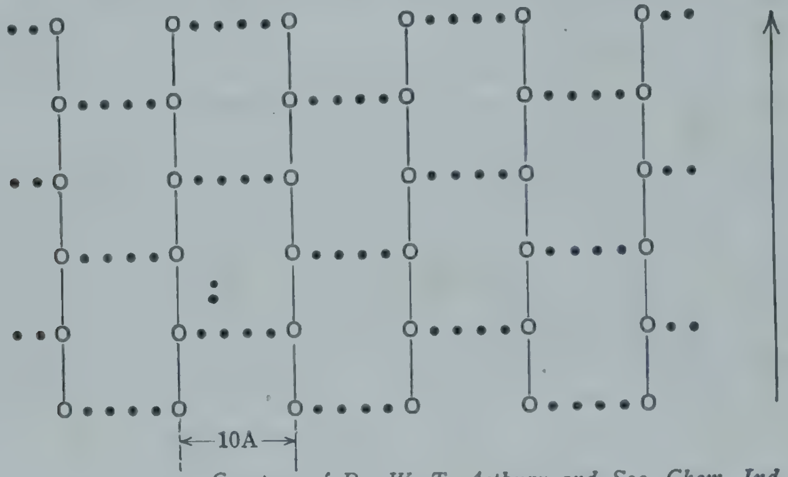


The R represents the amino acid residue. For glycine this would be a hydrogen molecule, for alanine a CH_3 group, for phenylalanine a benzene ring, and so on according to the configuration of the particular amino acid. The amino acid residues lie alternately on opposite sides of the backbone.

Types of proteins. Proteins are divided into two types: (*a*) the fibrous (represented by silk fibroin, collagen, muscle myosin, and keratin of hair); and (*b*) the corpuscular, globular, or crystalline proteins (exemplified by egg albumin and hemoglobin). However, Astbury (27) states there is no sharp distinction between the configuration of the two types of proteins, for the differences can be eliminated by denaturation.

The fibrous proteins are again divided into two groups, those in which the fiber is in folds or coils and is elastic such as myosin and keratin and those in which the chain is extended and the fiber is relatively inelastic such as silk fibroin and collagen. According to Astbury, x-ray analyses reveal three principal configurations for the fibrous proteins, perhaps for all proteins. They are (*i*) the folded or α-configuration of the unstretched fibers of the keratin-myosin group, (*ii*) the *trans*- or β-form which the α-form assumes reversibly upon stretching, and (*iii*) the mixed or *cis*- and *trans*-configuration of the collagen group.

Configurations of the protein molecule. Many structural configurations have been proposed for the protein molecule. Low (38) states that the early work of Astbury and coworkers has provided the foundation for most subsequent stereochemical theories of protein structure. Astbury (27) thinks that the experimental and general structural conditions are satisfied for the α-β configuration as follows: "(*a*) the α-form must be about half as long as the β-form. (*b*) The density must remain practically the same. (*c*) The folds [coils] must repeat at a distance of about 5.1 A. (*d*) The side chains must stand out alternately on one side and another of the plane of the fold. (*e*) The folds must be nowhere so sharp as to leave insufficient room for the side chains."



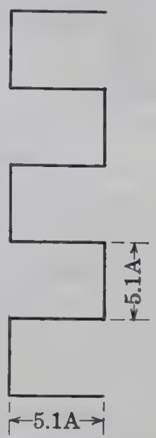
Courtesy of Dr. W. T. Astbury and Soc. Chem. Ind.

FIG. 2. Diagrammatic representation of a polypeptide "grid," "lattice," or "scaffolding," structure of the β-configuration of myosin and keratin. From *Chemistry & Industry, 60:* 491–497 (1941).

Pauling, Corey, and coworkers (43) have proposed helical configurations for the structure of the α-forms of keratin and myosin; a pleated sheet structure for the β- or stretched forms of proteins of hair, muscle, and related proteins; a combination of the α-helix (3.7-residues) and pleated sheet for feather rachis keratin; and three polypeptide chains coiled into an α-helix for collagen. In the helical configurations the side chains are outwards towards the perimeter of the coil.

The β-configuration, in terms of Fig. 2, is formed by throwing the main chains in folds undulating above and below the plane of the paper, so that operations of extension and contraction, no matter how often repeated, leave the integrity of the grid unchanged. A side view of these folded chains is shown diagrammatically in Fig. 3. The configuration in Fig. 3 leaves the density the same, the length half as long as in the β-form and the R residues on alternate sides of the chain. It also meets the conditions for making a fold, yet leaving room for the amino acid residues. The tendency for close packing of these residues is slightly greater than needed. Folds at 5.1 A result in the shortest distance possible that leaves side chains alternately on one side and the other permitting a reversible transformation without disrupting the structure.

Astbury advances the hypothesis that the corpuscular proteins are systems of polypeptide chains folded in specific configurations. He states that they are probably fibrous with chains folded in large, rounded, and usually unstable packets that have so far given no direct clue as to their shape inside. This hypothesis is supported by x-ray and other evidence.



Courtesy of Dr. W. T. Astbury and Soc. Chem. Ind.

FIG. 3. Diagram of Astbury's proposed basis of an intramolecular fold in α-keratin and α-myosin.

The sequences of amino acids. According to Low (38) the sequences of amino acids have been determined only for insulin. When these sequences have been determined for all proteins, the complete polypeptide chain model can be made for these proteins. The amino acid sequence is one of the determinants of the reactivity of the molecule. The amino acid composition has been determined for many proteins.

Cross links of polypeptide chains. The long polypeptide chains must be bound to each other with cross linkages to form proteins. These are represented by the dots in Fig. 2. There are several ways in which this may occur. Each amino acid has a carbonyl or ketone (C═O) as well as an imino (NH) group in the backbone of the peptide chain. These groups are polar and are attracted to each other by electrostatic forces. However, if these groups can come close enough together they may be held together by a hydrogen atom forming a hydrogen bridge or bond. Evidently some of the properties of proteins can be ascribed to this hydrogen bridge. The effect of increase in temperature on the hydrogen bonds may explain the liquefaction of gelatin. Myers and France (21) ascribe the thixotropic properties of egg albumin to the hydrogen bridge. On shearing or stirring, some of the hydrogen bridges which hold the lyospheres surrounding the dispersed particles are weakened and broken so that the gel becomes more liquid. When allowed to remain at rest these hydrogen bridges reform, the gel becoming stiffer.

The residue or side chains may also form cross links. Some of the side chains contain COOH, NH_2, and NH groups in addition to those in the backbone chain. These groups may interact to form salt bridges. The cystine of side chains may also form links, though it is not so important as other links because of the small amount of cystine found in most proteins.

Molecular weights. If the analysis of a protein shows that it has 36 units of a particular amino acid and that these 36 units constitute $\frac{1}{16}$ of the total units of the protein, then $36 \times 16 = 576$, or the number of individual amino acid units in the protein molecule. The weight of the smallest protein molecule that has been reported is about 17,600. It should contain 144 amino acid units. However, it is generally thought that the smallest number of amino acid units in most proteins is 288. The corresponding molecular weight is 35,000 to 36,000. Egg albumin, pepsin, and insulin belong in this group. In general, the number of amino acid units in any protein is thought to be a multiple of 288. Blood globin and fibrin each have 576 amino acid units with molecular weight of 70,000. Silk fibroin contains 2592 amino acid units. The molecular weight of silk fibroin and similar proteins runs into the millions.

Denaturation and Coagulation of Proteins

Neurath et al. (41) have published a comprehensive review of protein denaturation with 418 references. Anson (26) has covered some of the chemical aspects. Most textbooks on biochemistry have material on denaturation of proteins. See Chapter 18 by Bull in Gortner's *Outlines of Biochemistry.*

Wu (47) in his early work defined denaturation as a change in "the natural protein whereby it becomes insoluble in solvents in which it was previously soluble." A later definition is by Neurath et al. (41): "Denaturation is any non-proteolytic modification of the unique structure of a native protein, giving rise to definite changes in chemical, physical, or biological properties." This definition excludes hydrolysis of the peptide bonds. The consensus favors the theory that the native corpuscular protein molecules consist of folded or coiled peptide chains which upon denaturation open up to give extended molecules with a minimum of intramolecular change. Since the complex chemical and physical structures of the proteins along with their diverse biological functions renders them susceptible to a variety of changes, any of which may bring about decrease in solubility (41), the term "denaturation" may be ambiguous unless all the conditions concerning the denaturation are specified.

Manner of bringing about denaturation. Denaturation may be brought about in many ways. Among the physical means are: heat, surface forces, freezing, pressure, sound waves, and irradiation. The effect of chemical compounds such as urea, guanidine salts, acetamide, formamide, some detergents, H and OH ions, and organic solvents has been extensively studied. Most of the chemical agents are not used in food preparation, an exception being alcohol in wines, etc. Some proteolytic enzymes may have denaturing effects.

Neurath et al. (41) state there may be various degrees of denaturation between the native and the completely denatured protein. This depends upon the extent the protein structure has been altered. This in turn depends upon the nature of the protein and the denaturating agent.

Heat denaturation occurs through cooking foods such as meat, fish, and eggs but it is also often used (consciously or unconsciously) in omelet, angel cake, bread, and other products to aid in obtaining a framework in the prepared food. The rate of denaturation by heat depends upon the temperature. Anson (26) states that heat coagulation of isoelectric protein takes place about 600 times faster when the temperature is raised 10°C. Bull (31) states that heat denaturation occurs in three steps. The first is the opening up of the protein molecule whereby sulfhydryl (SH), disulfide (S—S), and phenol groups not detectable in the native protein become so in the denatured one; the second involves the flocculation of the protein; the third step results in coagulation and the insolubility of the denatured protein. Coagulation is very rapid at high temperatures as is evidenced by the coagulation with change in color of egg white. The temperature of coagulation varies with different factors such as the amount of water present, the salts present and their concentrations, the *p*H, and the presence of sugar. A dried protein (33, 41) can be exposed to as high a temperature as 120°C without losing its solubility. Pence et al. (44) determined the effects of time, temperature, moisture content, *p*H, and salt concentration on denaturation of gluten. They found the rate of denaturation at 80° and 90°C were negligible at low moisture contents, but rose rapidly to maxima at 35–40% moisture.

That *p*H, salts, and their concentration, as well as the presence of sugar, have some influence in the heat coagulation of proteins can be shown with custards. Sugar elevates the temperature for coagulation of egg protein. Dextrose and certain salts (28) are said to disperse heat-coagulated proteins. Native proteins have a *p*H range in which they are stable (41); outside this range denaturation may occur. The effect of a high *p*H (for food preparation) may be shown in using deteriorated egg whites. The whites of such eggs may reach a *p*H 9.0 to 9.5. A higher temperature is required to coagulate this white than the fresh egg white.

Surface denaturation. Bull and Neurath (30) find that the rate of surface denaturation for ovalbumin is dependent upon the concentration, being slower with higher concentrations. It is also dependent upon *p*H and is most rapid at the isoelectric point.

Surface denaturation cannot proceed to any appreciable extent without new surfaces being formed (30, 46). This would be expected since the protein remaining in the surface represents the lowest free energy. These same investigators have also reported that the protein molecule becomes more hydrophobic during surface denaturation, which is in accordance with the theory of denaturation and other types of denaturation.

Typical examples of surface denaturation are the insoluble portion of beaten egg whites and the foam on milk. When egg white or milk foams are allowed to remain undisturbed, they gradually collapse and the wrinkled membranes, skin, or films may be observed through the microscope. It has already been mentioned that protein can be recovered from a solution by removing the foam (23).

Clayton (34) states that high concentration of sugar in egg white will prevent surface denaturation. This can readily be demonstrated in the laboratory. Egg white to which sugar is added before beating is started forms a foam less readily. With a high-speed motor-operated beater it is very easy to overbeat and thus overcoagulate the egg white. Such egg white is not extensible in the oven and collapses to too great an extent. If addition of sugar to the egg white is started a few seconds after the beating is begun, surface denaturation is delayed and a better product is obtained.

Freezing. The *p*H, salt concentration, and freezing temperature (41) appear to influence the rate and extent of denaturation.

Pressure may develop to such an extent in a large piece of frozen meat that it may aid denaturation.

Differences in native and denatured proteins. A native protein has certain specific properties through which its role in living cells or its potential role in growth and development is played. When the protein is denatured these properties are lost. Since the precise structural configurations of the native and denatured proteins are not known, denaturation is described in terms of the changes in properties, rather than in terms of structural changes. Although the changes listed tend to be associated, all proteins undergoing denaturation do not show every change. These characteristics for the denatured protein include: (*a*) decrease in solubility; (*b*) an increase in the reactive SH, S—S, and phenol groups; (*c*) loss of biological specificity and modification of immunological properties; (*d*) loss of ability to crystallize; (*e*) increased viscosity of the protein (in egg white increase in rigidity is a more accurate description); (*f*) changes in molecular shape; (*g*) increased digestibility; and (*h*) a better defined x-ray pattern.

SH, S—S, and phenol groups. The detectable SH, S—S, and phenol groups (26, 39, 41) for most proteins are increased during denaturation. In complete denaturation the detectable thiol groups are equal in number to those obtained by hydrolysis. In most native proteins either none or a smaller number of these groups are detectable by color and oxidation-reduction reactions than in the denatured ones. In the native protein the SH, S—S, and phenol groups are held in the interior of the molecule by structural configuration but become detectable when the denatured molecule unfolds.

Enzymes are often heat-inactivated for better keeping quality of frozen vegetables, frozen milk, ice cream, and other food products.

Digestibility of denatured hemoglobin is more rapid than in the native (37). Clifford (35) found that cooked beef is digested more rapidly than raw beef. The rate of digestion of denatured egg albumin is faster than that of the natural egg albumin (47). Cohn and White (36) found that heating egg white for 30 minutes increases its rate of hydrolysis by trypsin and also by successive action of pepsin and trypsin. Proteolytic enzymes should be able to attack unfolded peptide links more rapidly than those of folded molecules.

X-ray patterns. Astbury (27) states that native proteins give hazy x-ray patterns whereas denatured ones give better defined patterns.

Renaturation of proteins. Fortunately for the mental equilibrium of the cook, the heat coagulation of most proteins is not reversible. Otherwise, many cooked dishes would, with certain treatment, revert to their original uncooked consistency. Some proteins may regain one or more characteristics of the native state but few are completely renatured.

Dispersion of Proteins

The term dispersion is used more frequently in the later, peptization in the earlier, literature. The meaning of the two terms as they are used is synonymous. Dispersion may be brought about by chemical, electrical, and mechanical means or by enzymes. The hydroxyl ion (7), citrate, acetate, and tartrate ions are effective dispersing substances. Different salts cause dispersion of varying amounts of wheat proteins. See p. 407.

Freundlich states that hydrophobic colloids and also solids may be peptized by suitable electrolytes, but the process does not take place spontaneously. It is necessary to divide mechanically the liquid or solid mass very finely, in order that the charging action of the peptizing ion may be effective. In some liquids it is often sufficient to divide them by energetic stirring.

Both the concentration of the electrolyte and its valence affect the extent of peptization. In general, the peptizing action is increased with increasing valence. For example, there is little peptization with the chlorine ion, the sulfate ion peptizes in higher concentrations, and the citrate ion brings about peptization with low concentrations.

The Browning Reaction

Maillard (56) was the first to describe the development of a brown color in mixtures containing amino acids and reducing sugars. Later it was shown that proteins as well as amino acids may react with the reducing sugars (61). This reaction between certain free groups of the amino acids of proteins, such as $-NH_2$, and a carbohydrate affects the compound in many ways in addition to the color change. It is known under various names: the Maillard reaction, protein-sugar, amino-sugar, amino-aldehyde, and the browning reaction.

Desirable effect. The browning reaction contributes to the aroma, flavor, and color of many foods such as ready to serve cereals, toffees, roasted coffee, malted barley, and baked goods (54). Bertram (49) has shown that the crust of bread does not brown as well if there is a shortage of reducing sugars in the dough. It has been suggested (48) that the browning reaction is a factor in the browning of breads and cakes and that it is responsible for the maple flavor developed in boiling the sap of the maple tree (64).

The amino acid. In using one amino acid with a single carbohydrate, Barnes and Kaufman (48) observed that the odor and flavor developed were characteristic of the amino acid being used. This has also been observed by other investigators. Thus glycine plus glucose resembles beer; leucine, fresh bread; and, amino butyric acid, maple flavor.

Undesirable effects. The undesirable effects of the browning reaction have been known in the sugar, beer, and malting industries. Many food products may be affected. These include dried foods such as milk, eggs, fruits, fruit juices, meat, fish, coconut, and vegetables (48); canned products such as milk, fruits, fruit juices, and juice concentrates; and, other foods such as molasses. Off odors, off flavors, and off colors develop in these foods. Each of these may be of varying degrees of intensity, depending on the stage to which the reaction has progressed. Under some circumstances the change may enhance the flavor of the product. Under other conditions the off flavor may be mild, stale, or become very bitter. The color may vary from light cream to nearly black. Coconut develops a saffron color (48).

The reaction. The over-all reaction of the amino acids or proteins and sugars is complex (48, 54). Many changes occur. Some of them are discussed later. The reaction also differs somewhat in diverse systems. Examples are egg whites with high protein and low sugar content and fruit juices with low protein and high sugar and acid content. Lea and Hannan (52, 55) in a series of papers in which the results of investigating casein and glucose have been reported, state that the primary reaction is between the free amino group with the aldehyde group. During this early part of the reaction the free amino content falls and the ratio of disappearance of free amino groups to glucose bound is practically 1:1. The reaction is slow and to some extent reversible. With time or with heating more complex changes occur. The brown color appears after a time lag during which the primary reaction has proceeded. During browning more glucose is bound than can be accounted for by the free amino groups and the product becomes insoluble over a wide pH range (54). Little is known of the secondary reaction(s) (48) except that the mixture becomes more acid.

Reactivity of the carbohydrate. The reactivity of the carbohydrates parallels the general reactivity of the carbohydrate compounds (48, 54). The aldopentoses react more rapidly or at a lower temperature than the di-, tri-, or polysaccharides. Carbohydrates having a free aldehyde group naturally react more rapidly than those sugars that have to be hydrolyzed or otherwise broken down to release this group. Xylose is about 40 times, whereas arabinose is about 20 times as reactive as glucose. Levulose reacts slowly.

The amino acids. The amino acids reported as involved in the browning reaction have varied somewhat with different investigators. However, the severity of the heat treatment of the mixtures used has varied in different studies. There is agreement that the amino group of any free amino acid reacts with the aldehyde group of the sugar. There is also agreement that, when a protein is involved, there is combination between the amino group of the side chain of lysine and the sugar. Mohamad et al. (57) think the guanido group of arginine is involved in the secondary reaction but the amide group is not involved. Lea (54) found in addition to lysine, that arginine, histidine, tyrosine, and methionine become involved in the casein-glucose mixtures. On acid hydrolysis all the tyrosine and methionine and part of the lysine and all the arginine and histidine are destroyed. Tryptophan is also involved (57, 58). Evans and Butts (51), in addition to the amino acids mentioned, found that cystine, aspartic acid, and glutamic acid are also involved.

Effect of temperature and time of storage, *p*H, and moisture content on the rate of browning. As the temperature is elevated the rate of browning is increased. Barnes and Kaufman (48) found that 3–4 hours at 100°C were equivalent to a week at 40°C. This amounted to a 2–3 fold increase for each 10°C rise in temperature. As the time of storage is increased browning and other changes increase in rate.

Lea (54) reports that the rate of reaction is almost linear with increasing *p*H, at least up to *p*H 8, possibly 10. Mohamad et al. (57) found browning is accelerated by increase in alkalinity. Barnes and Kaufman (48) found the rate of browning is doubled at *p*H 6 as compared with *p*H 4.

In a casein and dextrose mixture, Lea (54) found that the reaction occurs most rapidly in a moist solid. The peak of the reaction was with about 13% moisture content. Lea states the moisture at this content appears to cover the surface of the solid. The concentration of the protein and the glucose also influences the reaction. With bovine serum albumin and glucose the browning was directly proportional to the protein concentration, except in the range 6–9% (57).

Changes in the protein-sugar system. In addition to the production of off odor, flavor, and color, other changes include loss of solubility of the protein, decrease in amino nitrogen, decrease in *p*H, loss of nutritive value, enhanced reducing properties, increased tendency to froth or foam, and the development of fluorescence (54). The fluorescence has been used as a test to indicate the progress of the reaction (60, 63). Barnes and Kaufman (48), working with a single amino acid and a sugar, noted change in optical rotation and evolution of CO_2 under some circumstances with the formation of an aldehyde corresponding to the amino acid but containing one less carbon. Loss of water was also noted at high temperatures.

The identity of the brown pigment and intermediate compounds has not been determined. Browning in fruit products results in formation of furfuraldehydes (62).

Prevention of browning. The use of SO_2 is the best method for prevention of browning in dried fruits, vegetables, and coconut. A low storage temperature as well as a low moisture content of the product delays the appearance of the brown color. If the *p*H can be shifted so that the product is more acid, browning is delayed. In dried egg one of the reactants, the glucose sugar, may be removed by fermentation or enzymatic action before drying. Packing in CO_2 or nitrogen does not delay the reaction.

Loss of nutritive value. Loss of nutritive value (54) occurs when the bond formed with the amino acid is resistant to the action of the digestive enzymes or is split so slowly that the amino may be released too late to supplement other amino acids absorbed after digestion. The effect of the browning reaction on the biological value of the protein has been investigated by Patton et al. (58, 59), Evans and Butts (51), Block et al. (50), Hodson (53), and others. Loss of nutritive value may occur (*a*) when the amino acids or proteins are heated with glucose or other sugars, (*b*) when baked products such as bread and cake are subjected to high temperatures during baking (crust) or when toasted, and (*c*) by storage of food products.

The loss of biological value of the protein by refluxing casein and glucose involves loss of lysine, arginine, and tryptophan (58); by heating soybean meal, lysine was most susceptible followed by arginine, tryptophan, and histidine. The amino acid groups involved are epsilon amino, guanido, indole, and imidazole, respectively. Autoclaving a protein-sugar mixture (51) brought about loss of lysine, arginine, cystine, methionine, and aspartic and glutamic acids.

Toasting and browning a cake mix specially prepared to yield 25% of its calories from protein (50) brought a drop in the protein efficiency from 3.3–3.5 in the uncooked mix to 2.4 when baked, and after long drying and toasting the cake slices to 0.7.

Hodson (53) showed that the loss of biological value in evaporated milk was influenced by the storage time and temperature. After storage for 2 years at 4°C no loss occurred; at room temperature there was slight loss of lysine and histidine; at 38°C there was loss of lysine and arginine after 1 year and large losses of lysine, arginine, tryptophan, and histidine after 2 years.

Hydrogen-Ion Concentration

The symbol *p*H is very commonly used in present-day literature. Some explanation of the term and its relation to hydrogen-ion concentration is desirable. Perhaps it will be best to review briefly what is meant by hydrogen-ion concentration. In a solution of hydrochloric acid in water, the molecule of the acid consists of an atom of hydrogen united to an atom of chlorine. Hydrochloric acid molecules are found in the solution, but not all the acid remains in the molecular form. Part of the acid molecules are ionized into hydrogen ions and chlorine ions, the degree of ionization depending upon the concentration; the more dilute the acid solution, the greater the percentage of hydrochloric acid ionized. The hydrogen ions are positively charged, and the chlorine ions are negatively charged. In symbols, the ionization of hydrochloric acid is expressed as follows:

$$HCl \leftrightarrows H^+ + Cl^-$$

When a substance is ionized in solution the solution conducts an electric current.

When water is ionized it gives both hydrogen ions and hydroxyl ions. Since the ionization of water is very slight, the amount of hydrogen and hydroxyl ions in a liter of water is not great.

$$H_2O \leftrightarrows H^+ + OH^-$$

In pure water the concentration of hydrogen ions and hydroxyl ions is equal at 22°C. As the reaction of water varies at various temperatures, the following discussion applies to room temperature or 22°C. The concentration of the hydrogen ions and hydroxyl ions is $\frac{1}{10{,}000{,}000}$ of a gram-molecular weight (mole) each per liter. A normal solution of hydrogen ions contains 1 gram-molecular weight (1 gram) of hydrogen ions per liter of solution; a normal solution of hydroxyl ions contains 1 gram-molecular weight (17 grams) of hydroxyl ions per liter of solution. A liter of pure water contains $\frac{1}{10{,}000{,}000}$ of a mole of hydrogen. This requires many figures to express as a fraction; so for convenience the concentration is expressed as follows: $\frac{1}{10{,}000{,}000} = 10^{-7}$. Again for convenience Sörensen proposed to disregard the minus sign and use the numerical value of the exponent 10 to express the reaction corresponding to the concentration of hydrogen ions.

Thus $\frac{1}{10{,}000{,}000} = 10^{-7} = p\text{H } 7$.

When the concentration of the hydroxyl ions is equal to that of the hydrogen ions, the concentration of hydroxyl ions is also $\frac{1}{10,000,000}$ of a mole or 10^{-7}. This is the neutral point. The term *p*H denotes the concentration of the hydrogen ions only. Sometimes *p*OH is used to denote the concentration of the hydroxyl ions. Thus, when the concentration of the hydrogen ions (*p*H) is 7, that of the hydroxyl ions (*p*OH) is 7. If the concentration of the hydroxyl ions is multiplied by the concentration of the hydrogen ions a definite product is obtained. In fractions this would be written thus:

$$\frac{1}{10,000,000} \times \frac{1}{10,000,000} = \frac{1}{100,000,000,000,000}$$

But in the exponential notation it is expressed as follows:

$$10^{-7} \times 10^{-7} = 10^{-14}$$

When the hydrogen-ion concentration in a solution is increased, the hydroxyl-ion concentration is decreased, so that the product of the concentration of the hydrogen and hydroxyl ions always gives 10^{-14}, and this is a constant for the product of these two ions. Thus in a solution that has a *p*H 6 the hydrogen ions exceed the hydroxyl ions but the product of their concentrations is the constant 10^{-14}. In a solution that has a *p*H 6 the concentration of the hydrogen ions expressed in fractions is $\frac{1}{1,000,000}$ of a mole of hydrogen. In the same solution the concentration of the hydroxyl ions is $\frac{1}{100,000,000}$ of a mole. The product of these two concentrations gives the constant. Expressed in exponential notation it is $10^{-6} \times 10^{-8} = 10^{-14}$. In a solution that has a *p*H 8 the hydroxyl ions exceed the hydrogen ions but the product of their concentration is again 10^{-14}. When the concentration of the hydrogen ions is *p*H 3 or 10^{-3} then the concentration of the hydroxyl ions is 10^{-11} and their product is again 10^{-14}.

Literally, the term *p*H means to a power. It is used to express the reaction of a fluid, that is, its degree of acidity or alkalinity, but it does not do this directly, as is shown in the above equations. It is an inverse logarithmic function, deprived of its minus sign. Experimentally it is determined electrometrically and is really a number obtained from determining the electromotive force (emf) of a substance in a suitable apparatus and, by using this value of the electromotive force in a formula, computing the *p*H.

Hydrogen-ion concentration refers to the concentration of the ionized or active ions per liter of substance. The *p*H value does not represent this directly but for all practical purposes may be taken as a value representing it.

The relation of hydrogen-ion concentration and *p*H values in solutions of varying normalities is given below.

TABLE 3

Solution	Grams of hydrogen ion per liter	*p*H value
Normal	1.0	0
N/10	0.1	1
N/100	0.01	2
N/1000	0.001	3
N/10,000	0.0001	4
N/100,000	0.00001	5
N/1,000,000	0.000001	6
N/10,000,000	0.0000001	7

The above arrangement shows that the *p*H value is not an arithmetical series or ratio but varies according to the logarithmic notation. Thus *p*H 2 is not one-half of *p*H 1 but one-tenth of it.

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The browning reaction

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CHAPTER 2

Food Acceptability

This chapter is written primarily for the student who is starting his first special foods problem and may have only the regular class periods in which the preparation and scoring of the product are completed.

The terms acceptable, unacceptable, palatable, unpalatable, and quality or lack of it are used to describe whether the consumer likes or dislikes given foods. Likes and dislikes are also associated with the kinds of foods to which the consumer is accustomed and such psychological factors as religion and race. Acceptance or rejection of foods is based largely on the stimulus of the sense organs of the individual. All the senses (even hearing in evaluation of the crispness and crunchiness of some foods) are used in the appraisal of food, but particularly those of sight, smell, taste, and touch. The tactile sense interprets not only the hardness but also the temperature of the food. Pain may be caused by condiments such as pepper. Two excellent references on the sensory organs are: *The Chemical Senses* by Moncrieff (17) and *Flavor* by Crocker (7). The latter book also has many suggestions on the sensory evaluation of foods.

Sight. The first appraisal of a food, unless one is blindfolded, is by sight. The color (attractive or discolored), the shape (natural or distorted), the size, and the surface (whether smooth, rough, crystalline, desiccated, wrinkled, slimy) all register impressions. Part of the acceptance of a food depends on how it looks. Because of its color it has been said that only a connoisseur likes black bean soup.

Odor. Odors are the properties of gaseous substances. Very small concentrations of some substances can be detected by smell. Odors have been classified in various ways. Crocker (7) cites various classifications of odors that have been proposed and discusses the Crocker-Henderson classification, which divides odors into four groups: fragrant, acid, burnt, and caprylic. Each odor is assigned 8 degrees of intensity.

Odors are perceived in the upper part of the nasal cavity. Crocker points out that, in ordinary breathing, the inspired air does not pass through this chamber where the odors are perceived and some method such as sniffing is used to force air into the upper passage. A study of the diagram of the nasal passage in the books by Crocker (7) and Moncrieff (17) indicates clearly why sniffing is important in analyzing odors and its importance to the beginner in evaluating odors of foods. People and animals (8) detect odor best when the air is moist and warm. The moisture and warmth of the mouth favor odor development. In swallowing, part of this air with its odorous substances is exhaled. Crocker (8) states that in this way it is often possible to detect the odor of a "weak-odored" food by way of the mouth when the aroma often cannot be detected by sniffing.

Different people have different odor thresholds, *i.e.,* they vary widely in the concentration needed to detect the odor of a given substance. The same person may be able, as shown by Blakeslee (3) to detect odor of one kind of flower and not that of another.

Spices or synthetic substitutes are used daily to add odor and flavor zest to foods. Some foods have a fragrance that needs no spice. Others, such as apples when freshly harvested, need no appeal except their own fragrance. After storage and loss of some fragrance, spice may enhance apple pie.

The distinctive aroma of many foods, such as celery and onions, may be lost by overcooking, use of too much water, or poor cooking methods. Emphasis should be placed upon methods of cooking that retain or develop aromas of food as well as the nutritive value. A person may absorb nutrients from the digestive tract but he eats foods.

Taste. The taste buds, located mainly in the tongue, carry the basic tastes to the nervous system. The tastes are sweet, sour, salt, and bitter. People differ in their taste thresholds, *i.e.,* they may require different concentrations of a basic substance for its identification. Some sugars taste bitter to certain people. In the angel cake experiments usually a fourth to a fifth of the class obtain a bitter flavor instead of a sour taste when the cream of tartar is doubled. Blakeslee (3) tested 250 persons with the rare sugar, mannose. About 15% found it tasteless; 20%, sweet; 10%, bitter; 55% obtained both a sweet and bitter flavor. Some substances like saccharin are sweet in very dilute solutions but bitter in stronger concentrations. It has been shown by several investigators (3) that the ability to taste phenyl-thio-carbamide is hereditary. To some persons it is tasteless, to others it is bitter.

Fabian and Blum (12) have reported that the basic tastes may be enhanced or depressed by the presence of other tastes. Salt in sub-taste-threshold concentrations reduces the sourness of acids, but to varying degrees. Sugars may also reduce the sourness of acids.

It would appear that a person who could detect very small concentrations of the basic tastes in pure solutions would make a good scorer for detection of optimum quantities of salt, sugar, or acid to be used in food. However, it has been shown that some persons who can detect very small quantities of salt or sugar in solution may require a very much higher concentration in a food. At present there is agreement that a scoring panel should be trained on the product that they are to score.

Flavor. The term flavor has been used in various ways, but it is usually applied to the over-all sensations obtained by odor, taste, and touch. The feel of some foods is an important factor in their palatability. Examples are the crispness of crackers and certain types of cookies, the smoothness of custards, and the velvetiness of cake crumb.

Objective tests. No objective tests can determine odor and taste of food. Some objective tests, however, yield information that substantiates subjective appraisals. Objective tests determine the color and maintain the color standards of manufactured foods. Subjective ratings of tenderness of pastry, angel or sponge cake and bread, and meat may be substantiated by tests on the shortometer, tensile strength apparatus, or the shearing apparatus, respectively. Thermometers, thermocouples, and/or thermostats can be used to control the temperature for cooking, the end point in cooking as in meat and cake, and the temperature of the ingredients during various stages of preparation. The specific gravity of foams, batters, and baked products can be determined. A low specific gravity is correlated with a large volume. The microscope can be used to determine the relation of texture to various quality factors. Haugh units may be determined for egg quality. Tenderometers, penetrometers, compressometers, and viscosimeters may be used in various tests with food. Many other tests could be listed.

Chemical Constituents of Foods

The chemical constituents that contribute to the flavor (aroma and taste) of foods have not been determined completely for all foods. Sugars, acids, salts, and bitter substances are found in foods and form the four basic tastes. But many substances, such as alcohols, aldehydes, diacetyl, furfural, ketones, and esters contribute to the aroma and hence the flavor of foods. Kirchner (16) has reviewed the literature on the chemistry of fruit and vegetable flavors to 1949. Crocker (9) lists some of the chemical substances contributing to the flavor of meat. Baker et al. (1) have investigated the substances contributing to the flavor of bread, and Bouthilet (5) has isolated some of the chemical constituents of chicken flavor. Moncrieff (18, 19) lists substances that contribute to the aroma of tea and coffee.

Methods of Food Evaluation

Each individual evaluates foods daily in terms of likes and dislikes. Sometimes comparisons are made between products of rival processors or between a product made at different intervals. Thus A's bread may be preferred to B's, and the cake baked last week is better than the one baked this week.

The terminology used in food acceptance tests varies with different investigators and with different time periods. Distinctions among foods made by the senses have been called organoleptic, psychometric, and sensory. The words objective and subjective have been used in various ways. The term subjective as used in this book refers to preferences or differences obtained by the use of the senses; objective refers to data obtained by physical, chemical, or microbiological means.

Tests are of two types: preference and difference. Acceptance or preference tests determine what a representative population prefers and require large numbers of people. Some are conducted on a national scale. Some food firms or processors have housewives, who are scattered throughout the territory in which the product is sold, test new and old products. The coded products are shipped to the housewife in unlabeled, plain containers.

Small panels are used primarily to detect differences in palatability factors of foods. They may also express preferences. Small panels may determine: (*a*) the best processing procedures; (*b*) preferable varieties; (*c*) preferable cooking temperatures with time for given temperatures; (*d*) the effect of substituting one ingredient in whole or in part for another, such as peanut flour for flour; (*e*) the effect on quality of using different kinds of milk, eggs, flours, fats, and sweetenings in certain food products; (*f*) the best storage temperatures for fresh and frozen foods and the length of time that they may be stored at these temperatures; (*g*) the effect of insecticides and fertilizers on flavor of foods; (*h*) the effect of feeds on flavor and keeping quality of meat. Small panels may also (*i*) develop recipes to use products, (*j*) compare competitors' products, and (*k*) aid in maintenance of quality control of a processing plant's food products, particularly when raw ingredients are obtained from a new source or are changed. Other problems may be added to this list.

Tests. Many articles and reviews on types of sensory tests, selection of panels, recommended procedures, and results of studies in the literature have been published. Dawson and Harris (10) list types of sensory methods, refer to the literature, and list 300 references. Boggs and Hanson (4) give a good presentation and review of sensory difference tests. Other articles are by Bengtsson and Helm (2) and Hopkins (14).

Ranking tests. The scorer is asked to rank samples in a decreasing or increasing order of some characteristic. Several qualities, such as flavor, texture, and tenderness may be ranked independently or one over-all rating may be made. Ranks are sometimes converted to scores.

Duo-trio test. This test is similar to the triangle test (20).

The triangle test. This test is often used to detect acuity of taste or smell in prospective panel members, in determining if differences exist between foods, and in testing panel members throughout a study. Peryam and Swartz's abbreviated and adapted instructions (20) for the triangle test follow: You will be given a warm-up sample. This sample is apt to taste different because it is first. Rinse your mouth with the water provided after this sample is tasted. Then you will be given 3 samples at 1 time. Of these, two are identical and one is different. You should proceed slowly, take as nearly as possible the same amount of sample in each taste, and rinse the mouth, and pause after each taste in order to avoid interference between samples.

Paired samples. Cover (6) used this method for scoring meat. The scorer was asked to determine which of two samples was the more tender. Only one dependent variable (tenderness) and one independent variable (the cooking temperature) were used.

Dilution tests. Dried egg was substituted in varying proportions for fresh egg in scrambled eggs. A fresh egg was used as a control. This method, developed by Bohren and Jordan, is given in detail by Boggs and Hanson (4).

Scoring tests. These tests are made more frequently than the other sensory tests. The scorer assigns a numerical rating to single palatability factors. The scorer is expected to detect differences in the samples, if differences exist, and to assign a quantity factor to these ratings.

Comparison of methods. None of the methods for determining sensory differences is entirely satisfactory. Preferential ranking is of value in determining acceptability but gives no evaluation of the particular gradation of quality as a permanent record. The triangle and paired tests show that differences exist, but again, no gradation of quality is obtained unless the differences of samples are also scored. Many comparisons under statistical evaluations may be made. The dilution test is not suitable with all products. In scoring tests the numerical evaluations are comparative and not absolute. A score of 8 does not imply that a palatability factor is twice as acceptable as one given a score of 4, or, in turn, one given a score of 4 is not twice as desirable as one given a score of 2.

A mediocre product tends to be graded high when placed with poor samples and low when placed with high-quality ones (11).

Some factors affecting accuracy of tests. Boggs and Hanson (4) list the following factors of the experimental plan as having primary effect on the accuracy of the results: (*a*) the characteristics evaluated, (*b*) cooking of the sample, (*c*) quality of the foods, (*d*) reference standards, and (*e*) replications. To the above should be added (*f*) the preparation of the product. Poultry and meat, unless aging is the variable being studied, should be aged to the same extent. Many products such as pastry, cakes, and baked products should be mixed at a definite temperature. Otherwise variation in the temperature of the ingredients and the batter or dough may cause greater differences in the product than the variable being studied. The length of time that the shortening is conditioned before use causes variations in the product. A room in which the preparation can be made and the temperature and relative humidity can be controlled is often an advantage. Other examples can be added to the above.

So many characteristics can be scored for a given product that the scorer is left in a daze. It is better to decide carefully what characteristics will give the most information and limit the palatability evaluations to only a small number. A total score obtained by adding the scores for all factors may be misleading, if, for example, all the scores are high except flavor.

The method of cooking may have a decided influence on the outcome of the experiment. Some decision must be made in planning the experiment to standardize the cooking method and the extent to which the product should be cooked to obtain a standard product. Cooking meat and custards to definite interior temperatures does not always accomplish this, particularly if the cooking temperatures and hence the rate of heat penetration vary considerably. See the discussion on p. 237. Often an arbitrary method must be chosen.

Since scores are based on human opinion, the validity of these scores may vary over wide intervals of time or from day to day. Hence a reference or control sample is of great value to the scorer. Sometimes more than one reference sample is used. The control sample may or may not be known to the scorer. Fresh poultry may be used with frozen poultry for a control; frozen strawberries kept at a very low temperature may be used as standards for those stored at higher temperatures; and fresh egg may be used with dried egg products.

The number of replications (4) needed for valid results depends on the variability of the samples, variability of the scorer's judgments, the extent of the differences among samples, and the extent of information wanted from the experiment.

Interrelationships of organoleptic factors. One of the major difficulties in evaluating sensory stimuli is the interrelationships of the palatability factors. Considerable discipline may be required to separate one quality factor from another. It may be difficult to score texture fairly when the flavor of a product is very poor. The dryness of very well done meat, because of difficulty of mastication, may make the meat appear tough.

Statistics. A study of quality differences in foods (not merely learning technics) should have the problem or experiment so designed that the data obtained can be evaluated statistically. Undergraduates who wish to work for industrial companies should take courses in statistics. Graduate students, in most schools, are required to take such courses.

Numerical Scores

The number of gradations in a scoring scale is important. Accuracy is not gained by using a scoring scale that has a range of differences in excess of the number of gradations of quality that can be recognized. Conversely, a scale that has a smaller number of gradations than can be recognized gives results of little value. In addition, in planning a scale for scoring, it should be remembered that some scorers seldom use the highest and lowest numbers of the scale.

Many scales have been utilized in evaluating sensory tests. A 0–100 scale with either a 1- or a 5-point difference was frequent 3 or 4 decades ago. This scale is seldom used at present for it is obvious that 100 gradations are more qualities than can be determined. Scales of 1–3, 1–4, 1–5, 1–7, 1–9, 1–10, or 0–3, 0–4, 0–5, 0–7, 0–9 and 0–10 have been used in evaluation of sensory tests and reported in the literature. Other scales have also been used. Boggs and Hanson (4) state that 10 scale intervals are usually sufficient. The trend in the literature appears to be the use of 9, 10, or 11 gradations, although the scale often varies with different foods. For example, the scoring scales used with dairy products are not like those listed, but have been used for several years. In addition to the individual palatability scores, an over-all score, *i.e.,* the order of preference based on all palatability factors is sometimes used. Platt (22) in 1931 suggested such a score using the descriptive term "eating quality" to describe it. Plank (21) discusses the use of numerical evaluations and states the number expressing the grade should be proportional to the quality of the property to be measured or an equal difference in scale evaluations should correspond with an equal difference in quality.

A descriptive term with each point on the scale that suggests the quality is an aid to the scorer. Terms that suggest a characteristic that is not likely to be found in the food product are misleading to the members of the scoring panel. The following or similar terms are often used.

GRADE	TERM (Plank, 21)	TERM (Ramsbottom, 23)	GRADE	TERM (Hopkins, 15)
10	Perfect (fancy)	Excellent	+5	Gross excess
9	Excellent	Very good	+4	Very decided excess
8	Very good	Good	+3	Decided excess
7	Good	Slightly good	+2	Moderate excess
6	Slightly good	Borderline plus	+1	Slight excess
5	Average	Borderline minus	0	Ideal
4	Fair	Slightly poor	−1	Slight deficiency
3	Borderline	Poor	−2	Moderate deficiency
2	Bad (defective)	Very poor	−3	Decided deficiency
1	Very bad	Extremely poor	−4	Very decided deficiency
0	Inedible		−5	Gross deficiency

The scale system of Hopkins (15) was designed for universal application. It was difficult for one panel in scoring meat in the author's laboratory, but it should be good to determine whether a product has an excess or deficiency of salt, sugar, chocolate, or other ingredients.

The Scorers

The panel. The same panel of scorers should be used throughout a given study. Sometimes in the statistical design a roving scorer is required, *i.e.,* one panel member is always different for each scoring. Giradot, Peryam, and Shapiro (13) cite the problems involved in panel selection. They emphasize (*a*) failure of the panel members to comprehend what is expected of them, (*b*) their poor "flavor memory," and (*c*) the importance of selecting panel members by using the product being investigated. For class problems the available personnel has to furnish the panel members. The majority of persons are average in sensory evaluations, some are superior, some are inferior, and some are taste or odor blind.

Various opinions have been expressed in the literature on the sex and optimum age of the scorer. Some consider age irrelevant, the results obtained depending on the individual. Health is important. A scorer should have emotional stability and be free of colds, allergies, and infections involving the sense organs.

The number. Since there are many sources of variation in sensory tests, it follows that, the more scorers on the panel, the more likely it is that the individual variations will balance. This is one of the basic tenets of statistical treatment of experimental data. Increasing the number of replications of the test tends to rule out the experimental error due to daily individual variations of colds or emotional or physical upsets.

Four scorers is probably the minimum number although some think it should be 8 or 10. More are desirable until a point is reached at which the additional material required and the time involved in preparation and analyzing of the data outweigh the benefits. A small panel of high sensitivity and ability to differentiate perceptions may be preferable to a large panel of less sensitivity.

Personal characteristics and habits. A person of average sensitivity, a high degree of personal integrity, ability to concentrate, intellectual curiosity, and willingness to spend time in evaluation of the scoring problem may do a better job than a careless person with extreme acuity of taste and smell.

The published reports have not shown discrimination between smokers and non-smokers in acuity of sensory perceptions. Smokers are usually asked to refrain from smoking for a period of time before scoring. The real difficulty in having smokers and non-smokers score at the same time is that the odor of the smoker's clothing distracts the non-smoker, unless their scoring places are far enough apart.

Training. A preliminary training period is considered desirable even for experienced scorers of a given product. This period aids in recalling and reestablishing degrees of variation. For the beginner it gives some training in evaluation of qualities, what to look for, and starts establishment of standards. An understanding of the problem and an interest in it generally increases the efficiency of the scorer. Daily scoring of a food over long periods of time may be disadvantageous because the scorer tires of the food. Training for a research panel may require considerable time, depending on the characteristics to be evaluated. Thus Boggs (10) states that for prospective panel members to score different quality factors of carrots with accuracy required 3 days for tenderness, 1 week for color, and 3 weeks for flavor. A round-table type of training with free discussion of the different characteristics is often advocated.

Smelling and tasting. Crocker (7) gives technics for organoleptic smelling and tasting. An unknown is smelled cautiously at first to avoid odors that may cause temporary injury. The scorer inhales strongly through the nose for 2–3 seconds with both nostrils open, although only one is used. Hands have ever-present odors; thus it is best to be seated in front of a desk or table and to bend the body forward until the nose is about a half inch from the food. A rotating table is useful.

Tasting is started after smelling is completed. The tempo of tasting should be slow, and a much longer time is required if the product clings like the yolk of raw egg. Bitter substances are detected more readily on the back of the tongue and the taste of some substances such as S.A.S. baking powder residue appears a short time after the food is swallowed. Sulfite in foods is also said not to be perceptible at first but the scorer must wait a short period of time after the food is swallowed. If samples are not swallowed it is easier to perceive some taste perceptions if the food comes in contact with the back of the tongue. Very hot peppers or strong sulfited foods should be arranged in order of increasing concentration of the substances. Some of these foods can incapacitate a scorer for a long period. If scoring such food is undertaken more than one roving scorer who does not record scores may be needed to put the foods in order of increasing concentration of the substance. The sense of taste recovers more slowly after fatigue than the sense of smell.

Various substances have been used to remove the flavor of one sample from the mouth before the second is tasted. Water, at room or lukewarm temperature, is most frequently used. Crocker (7) states that the best general technic is to allow the saliva to clear the tongue in a natural manner.

The sensitivity of taste (17) is about doubled by raising the temperature of the food from 10–20°C, remains about the same between 20° and 30°C, but falls with further increase of the temperature. Thus it is important to score foods at the same temperature from day to day.

The Problem

Selection. A student should select a problem in which he is interested. Practically, the selection may be influenced by several factors. Among these are: (*a*) The length of the class period; the product must be prepared and scored in the allotted class time unless the experimenter is able to give additional time to the problem. Sometimes a product that requires long preparation, such as cake, can be made during one period and stored until the succeeding class period. If this period is more than 2 days the product should be frozen. Other products may be refrigerated 24 or 48 hours. In most classes the student will need to allow time to score products of other students in return for the privilege of having her own scored. (*b*) The amount of equipment available: if a student wishes to use 4 ovens to compare the effect of different baking temperatures on a product, there must be enough ovens for other members of the class. (*c*) The length of the experimental period; if this period lasts 3, 6, or 12 weeks and prepared frozen foods are to be stored, the storage periods need to be regulated accordingly. (*d*) Can the ingredients be obtained by the time the problem is started? This kind of experiment should be planned long enough ahead to allow the ingredient to be obtained. (*e*) The other products made in class; if every member of the class selects a cake problem, scoring will become monotonous, even if only products of 3 class members are scored by a given student.

The variables. A beginning student often plans too many variables to be evaluated in the experimental study. Usually, only one variable should be used. If the optimum proportion of an ingredient, such as fat, egg, sugar, flour, or liquid, is to be determined, products with varying proportions of the ingredient will need to be prepared. If some kind of ingredient is to be substituted in part for another constituent, such as soy flour for part of the flour, again varying amounts of this ingredient will need to be used. The variables that may be used are many in number.

The number of products. The number of products that can be prepared and scored in a given class period varies with the particular product. Rolls and cakes take longer to prepare and to cool than most vegetables. Usually no more than 3 or 4 products should be prepared in a given class period. Prepare enough of each sample so there will be sufficient for your scoring panel. Each scorer should receive at least 1 muffin or biscuit, 1 lamb chop, a slice of cake, or a half slice of roast beef.

The outline of the problem should be presented to the instructor for constructive criticism before the preparation of the product is started. The outline should include the object of the study, the variables to be used, the method of procedure, the score card, and the ingredients needed.

Practice periods. There are decided advantages in keeping the first problem short. Much is learned about planning the problem, the time needed for preparation of the product and samples for scoring products of class members, using other score cards, and writing the results of a problem. This background is valuable in planning a longer problem. Often mistakes or procedures that would handicap a longer problem can be avoided. In the author's laboratory the first class problem is done in 7 class periods, the second in 20 or 22 class periods. Since routine procedures are not organized, long experience has shown that it is wise to use the first class period of the short problem as a practice period. Not all the products are prepared this first day, only enough to have some to score. Errors in calculation and time or other factors may be corrected for the 6 following periods. For the longer problem, depending on the time allotted for the problem, from 1 to 3 or more class periods may be required in preliminary tests.

The results. The completion of the problem is the writing. The written problem may be divided as follows: (*a*) the object of the experiment, (*b*) the method of procedure (which includes the recipe, the proportion of ingredients, the equipment, as well as the procedure), (*c*) the results, and (*d*) the summary and/or conclusions. A review of the literature or of former problems may be included. Consult your instructor in regard to the completeness desired in the method of procedure. A complete method would give the details so that another student could follow them. The data for each palatability factor are averaged and compiled into graphs and tables. Objective data are also compiled. For beginning problems graphs that show both the daily variation as well as the average are helpful. When the daily variation is wide, little emphasis should be put on small differences in averages.

The results are discussed. In the discussion the results of your problem may be compared with those reported in the literature. If copies of previous problems done in your laboratory are accessible, your results may be compared with those of previous studies. If your results are similar to those obtained in other problems they carry more weight. For example, if the desirable amount of soy flour to be substituted for flour is less than 5% and the same result has been obtained in several short problems, the combined results may be as valid as those of a long study.

A 7-period class problem is not sufficient time for adequate training of a panel or to establish standardized procedures. A typed copy is handed in for grading. In some laboratories, this copy is retained, bound in temporary or permanent binding, and kept so that succeeding students can compare results with those obtained for their problem.

Responsibility of the Person Doing the Problem

Certain observations concerning a product only the director (the person doing the problem) can make and record. They include such items as the initial temperature of meat at the start of cooking; the initial and final weights; the temperature of ingredients during mixing or preparation; the appearance of the product before cooking, such as curdling or smoothness of a cake batter or the desiccation on the skin of poultry; the consistency of the product (thin, thick, rough, smooth); the time for cooking; the weight losses during cooking; the humidity, which may bring about stickiness of candy or a cake crust; in fact, all the factors that may bring about or explain variations in the finished product. The recording of data at the appropriate time is usually a discipline that the experimenter must cultivate. Too often one intends to record observations later and then forgets them. It is better to err in recording too much data than "too little and too late."

The score card. The score card should be neat. It should have a place for the name of the scorer, the date, and code number of the product. Confusion from using the same number again can be avoided by numbering the products consecutively. If the palatability factors of the food product are to be scored numerically, the numerical scale should be clearly stated as well as the descriptive terms that accompany the gradations. The director should discuss the score card with the panel. Part of the time of the practice periods can be used for this.

Preparation of the samples for scoring. The samples for scoring should be presented in an attractive manner. Their appearance is the first advertisement of the product to your panel. If dishes are used they should always be the same shape and color. Each dish will need the code number of the product; but putting the code number on the bottom of the dish and placing the product over it not only are messy but also may annoy some members of your panel. Paper or other products that may give the food an off flavor should be avoided. Serving silver, if needed, and a glass of water at room temperature are added to the tray containing the samples. It is best not to present the samples in the same order on the tray throughout the study.

Samples should be prepared carefully. Whole potatoes, apples, and like products may be quartered or cut so that some of both stem and blossom end are given to each scorer. Slices of bread, cake, and meat come from certain locations for each scorer. For example, the end slice of a cake is not scored, the second slice is used for scorer A, the third for scorer B, and the sixth for moisture absorption tests and so on. Samples of some products like meat, cake, and bread should always be approximately the same thickness. They may be cut on a slicer, or bread and cake may be cut in a miter box.

The samples should be ready at the time at which they are to be scored. Some samples such as cake or bread can be cut a short time in advance of scoring, if each slice is wrapped separately in cellophane, foil, or slipped into a small plastic bag to prevent drying of the product.

The scorer should not be rushed, annoyed, irritated, or interrupted after he starts scoring. An example of annoying some members of the panel follows. A student was making a statistical assessment of a panel's ability to distinguish replacement of different concentrations of fresh egg by dried egg in custard. The custards were tasted when they cooled to a certain temperature 15 to 30 minutes after the class period was over. Half the panel members resented this delay, and hence did not score as well as the two scorers who did not object to the delay. It did not occur to the experimenter that she was imposing on the panel and that she should have come to start her preparation before the beginning of the class period.

The collecting of the score cards, as well as washing the scoring dishes and utensils, are the director's responsibility.

Responsibility of the Scorer

If a given food is nauseating to a person he should not attempt to score it. If he simply dislikes it, he should not score it unless he can be objective and conscientious about evaluating the product. One of the best scorers the author has known did not particularly like certain foods but was objective in evaluation of the product. It is not uncommon for a person to tire of a food that he particularly liked before starting the scoring or to develop a liking for a food he had not cared for. In either of these eventualities the established standards for grading should be maintained, unless the product has become better or has deteriorated with continued preparation.

When a person accepts an invitation to be on a scoring panel he accepts certain responsibilities. He accepts giving sufficient time to do the job well; concentrating and using his sensory organs to distinguish differences in aroma, taste, texture, tenderness, and moistness that are characteristic of an excellent product of the food type being scored and for which the director of the problem is obtaining information. It is legitimate to use previous score cards in memorizing standards. A person may know that the sample being scored is better than the one at a previous scoring, yet may not remember the numerical evaluation given previously for a certain quality factor.

The scorer should be seated, should be comfortable, and should not be interrupted during the scoring process. If the experiment is one in which the object of the experiment is known to the scoring panel, the director of the experiment may be asked the identity of different samples after the scoring is completed. This aids in fixing standards. Good procedure is to list the criteria used in scoring a product. The score card, its terminology, and what the director of the problem wishes recorded should be clear. Each quality of every sample should be checked to see that all have been scored. If some palatability factor is omitted it leaves a gap in the director's data. One should be thorough about making comments, if comments are indicated as desirable.

The scorer should inform the director of the experiment when he has a cold or is otherwise incapacitated in doing a good scoring job. This can be written on the score card under comments.

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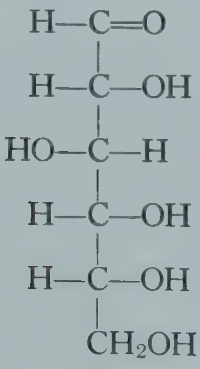
CHAPTER
3

Sugar Cookery

Classification of the Carbohydrates

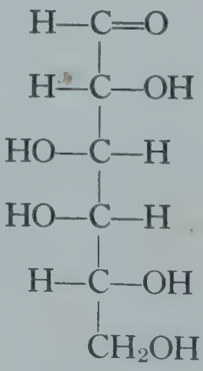
Carbohydrates (19, 32, 50) are divided into three groups, mono-, oligo-, and polysaccharides, on the basis of their hydrolysis products. Monosaccharides contain one, oligosaccharides two, three, or four, and polysaccharides many saccharide or sugar groups. The oligo-, and polysaccharides yield monosaccharides on hydrolysis.

The monosaccharides are polyhydroxy compounds, and are classified according to the length of the carbon chain and the presence of either aldehyde or ketone grouping in the molecule. The smallest monosaccharide is a diose having 2 carbon atoms, 1 with a carbonyl group, the other with a hydroxyl group attached. The largest that has been synthesized is a decose with 10 carbon atoms. The common monosaccharides in foods are the hexoses, and of these the commonest are dextrose, galactose, and fructose. The first two are aldoses, the last a ketose. The carbons (19) are numbered, beginning at the top, the ketose being on carbon 2 of *d*-fructose.



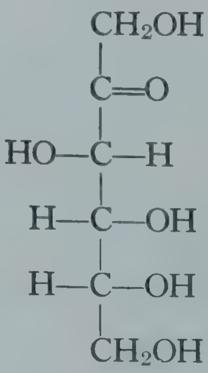
$$\begin{array}{c} \mathrm{H-C{=}O} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{HO-C-H} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

d-Glucose



$$\begin{array}{c} \mathrm{H-C{=}O} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{HO-C-H} \\ | \\ \mathrm{HO-C-H} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

d-Galactose

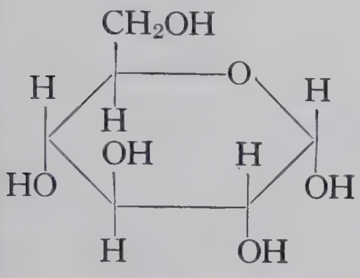


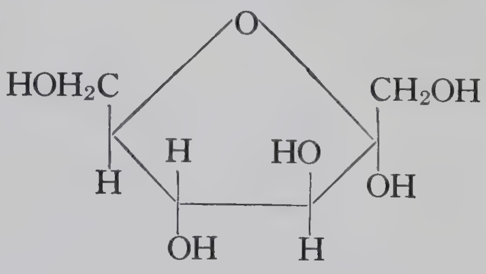
$$\begin{array}{c} \mathrm{CH_2OH} \\ | \\ \mathrm{C{=}O} \\ | \\ \mathrm{HO-C-H} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

d-Fructose

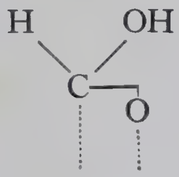
The *d* indicates that the hydroxyl group on the fifth carbon atom is placed on the right. If it were on the left, the sugar would be an *l*-hexose. This does not indicate the optical rotation, which is designated by the prefixes dextro and levo.

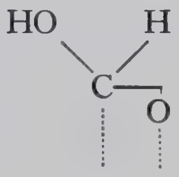
All the monosaccharides (19, 26, 50) above tetrose may assume two structural ring forms, the pyran and the furan. The pyranose ring consists of 5 carbon atoms and 1 oxygen atom, the furanose ring of 4 carbon atoms and 1 oxygen atom. The pyranose ring is the one usually present in common sugars, with the exception of fructose in sucrose, which has the furanose ring.


α-*d*-Glucopyranose


α-*d*-Fructofuranose

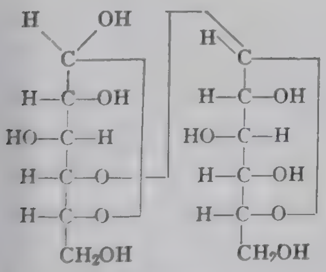
The designation (19) α or β is added to indicate which of the two possible stereoisomeric forms is assumed by the linkages on the carbonyl group.

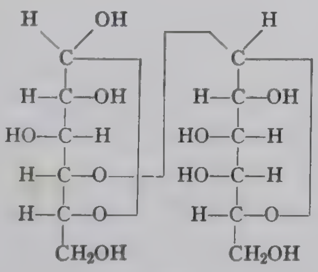

Alpha

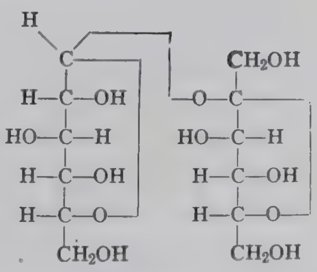

Beta

The oligo- and polysaccharides are formed by the union of two or more monosaccharides with loss of water. The oxygen atom connecting the saccharide units may be connected in several ways: to the reducing groups, as in sucrose; from C_1 of one unit to C_4 of the next, as in maltose, lactose, and cellobiose; and from C_1 of one unit to C_6 of the next, as in gentiobiose and melibiose. The linkage may be either alpha or beta.

The common disaccharides found in foods are sucrose, maltose, and lactose. Sucrose is composed of one dextrose and one levulose group; maltose, of two dextrose groups; and lactose, of one dextrose and one galactose group.


Maltose


Lactose


Sucrose

Starch (26) is formed by the union of many α-glucose units.

Below are listed the common carbohydrates used in foods. For a complete list consult a physiological or an organic chemistry (19).

MONOSACCHARIDES	DISACCHARIDES	POLYSACCHARIDES
Dextrose or glucose	Sucrose	Dextrins
Levulose or fructose	Maltose	Starch
	Lactose	Cellulose
		Pectins
		Gums

Sources and Uses of the Common Sugars

Dextrose or glucose is widely distributed in fruits, honey, and some vegetables. Most of the commercial crystalline dextrose is made from corn. It is produced in two forms, a hydrated containing about 9% moisture, and an anhydrous containing about 0.2% moisture (34).

Corn sirup also contains glucose. Cornstarch is converted to dextrins and sugars by acid or enzyme hydrolysis or a combination of both. The resulting product may be a high- or low-conversion sirup (in high conversion more dextrins are converted to sugar). Sirups made from wheat, corn, waxy corn, tapioca, and potato starches are said to be nearly identical in appearance and flavor (10).

Levulose or fructose is also widely distributed in natural foods, often accompanying dextrose, or dextrose and sucrose. At present, pure crystalline levulose is expensive. Honey contains nearly equal parts of dextrose and levulose. When honey crystallizes, the greater part of the levulose is in the sirup and the dextrose in the crystals.

Sucrose is widely distributed in plants, often with dextrose and levulose. The common commercial sources of it are the sugar beet, the sugar cane, the sugar maple, and the sugar palm. It is the common granulated sugar on the market and is practically pure whether obtained from the beet or cane. Maple sugar is not purified, for it would then lose the flavor for which we prize it.

Maltose is formed as an intermediate product when starch is hydrolyzed by boiling with mineral acid in the manufacture of corn sirup from corn. Commercially it is prepared from starch by a diastatic enzyme, and it is also found in germinating cereals and malt products.

Lactose is obtained from milk. One of its uses is for infant feeding.

Uses. Sucrose is commercially the most important of the sugars, being used for sweetening purposes in far larger quantity than the other sugars.

Some uses of dextrose are in canned foods, preserves (6, 16, 33, 48), ice cream (11, 12), and in confectionery (34). Corn sirup is used in jams, preserves, canned fruits, and confectionery.

Maltose (15) is used in confectionery and for industrial purposes. Lactose (44, 39) is also employed in confectionery and to some extent in industry (14). The rare sugars (20) are used for scientific purposes.

Meeker (34) discusses the uses of the following sweeteners in confectionery: sucrose, inverted and uninverted sucrose sirups, dextrose, and corn sirup. He stresses the importance of knowing the composition, properties, reactions, and characteristics of the different sweeteners, so that they may be used most efficiently in confections. Each sweetener has special characteristics and differs from the others. For example, corn sirups vary in composition, Table 4. A high-conversion corn sirup is sweeter but less viscous than a low-conversion one. D.E. stands for "dextrose equivalent." This is the reducing power of the solids in the sirup calculated and expressed as dextrose. The Baumé degrees are determined at 37.8°C.

TABLE 4

Approximate Composition of Corn Sirup, Wet Basis (*Meeker*)

	Types			
	Regular 43° Baumé 42 D.E. %	Medium conversion 43° Baumé 52 D.E. %	High conversion (dual acid-enzyme) 43° Baumé 63 D.E. %	High conversion (straight acid) 43° Baumé 60 D.E. %
Moisture	19.7	19.0	18.5	18.5
Total solids	80.3	81.0	81.5	81.5
Dextrose	18.0	26.0	30.5	33.0
Maltose	17.0	21.0	28.0	23.0
Higher sugars	16.0	11.0	13.0	6.5
Dextrins	30.0	23.0	10.0	19.0
Ash	0.3	0.3	0.3	0.3
*p*H	4.7–5	4.7–5	4.7–5	4.7–5
Poises *	160	104	60	80

* Approximate relative viscosity at 100°F.

Relative Sweetness of the Sugars

Sweetness is a quality that is detected by taste, but there is no exact test for it. Much depends upon how the test is conducted, whether the tongue is dry or moist, upon what part of the tongue the sample is placed, and, with several other conditions, the fatigue of the sense of taste. In addition to the foregoing, Cameron (8) found that the relative sweetness varied with the concentration of sugar in solution; that relative sweetness is affected by the temperature of the substance being tasted, the intensity of sweetness being increased as the temperature is raised. The optimum temperature for detection of the sweet taste is said to be 35–50°C, although

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this varies with individuals. Cameron also found that, in solutions in which mutarotation can occur, the freshly prepared solution is sweeter than after the solution has stood 16 hours. Some persons detect sweetness in weaker concentrations than others. It cannot be expected that all people will agree in their estimates of the relative sweetness of the sugars, even with carefully worked out tests (2, 13, 42).

In rating the sweetness of the various sugars it is a commonly accepted practice to rate sucrose as 100. Sugars sweeter than sucrose are ranked higher than 100, and those less sweet are ranked lower. See Table 5.

TABLE 5

RATINGS FOR RELATIVE SWEETNESS OF SUGARS

SUGAR	BIESTER, WOOD, AND WAHLIN (2)	SALE AND SKINNER (43)	PAUL (38)
Levulose......	173.3	150	103
Sucrose.......	100.0	100	100
Dextrose......	74.3	50	52
Maltose......	32.5	60	..
Lactose.......	16.0	..	28
Invert sugar...	....	85	..

Most investigators indicate that levulose is the sweetest sugar. Cameron gives the concentrations of the different sugars to give equal sweetness, Table 6.

TABLE 6

CONCENTRATIONS OF SOLUTIONS OF SUGARS TO GIVE EQUAL SWEETNESS (*Cameron*)

SUCROSE %	GLUCOSE %	FRUCTOSE %	LACTOSE %	GALACTOSE %
2.0	3.8	...	6.5	...
2.5	...	...	...	5.0
3.35	...	3.0	...	...
5.0	8.3	4.6	14.9	...
5.5	...	5.0	...	...
6.0	...	...	...	10.0
8.0	...	...	21.7	...
10.0	14.6	...	...	15.0
17.8	...	15.0	...	...
20.0	25.0	...	...	...

Effect of Acid upon Sugars

Strong concentrated acids decompose all the sugars, producing humic or caramel substances. The effect of weak acids depends on the size of the carbohydrate molecule, the kind and strength of acid, and the temperature and duration of heating. The principal action is hydrolysis, so that weak acids have very little effect on monosaccharides. Of the disaccharides, sucrose is hydrolyzed very easily, maltose less easily, and lactose only slowly. Starch is readily hydrolyzed by dilute mineral acids.

The hydrolysis of sucrose, readily accomplished by enzymes or weak acids, is often referred to as inversion, because of the change in rotatory power of the solution. If a beam of light is passed through a solution of sucrose in a polariscope, the light will be rotated to the right, and so sucrose is dextrorotatory. Dextrose is also dextroratatory, but levulose is levorotatory (rotates light to the left). Levulose has a stronger rotatory power than dextrose, so that the mixture of levulose and dextrose resulting from the hydrolysis of sucrose is levorotatory (the rotation has been inverted) and the mixture is called invert sugar.

Hydrolysis of sugars by enzymes. Enzymes also bring about hydrolysis of oligo- and polysaccharides. Since heat destroys enzymes the reaction must occur at a low temperature. The enzyme invertase causes hydrolysis of sucrose to dextrose and levulose, maltase hydrolyzes maltose to dextrose, and lactase converts lactose to dextrose and galactose.

Weak acids and sucrose for fondant. The weak acids used in cookery, lemon juice, vinegar, fruit juices, or the acid salt cream of tartar, all cause inversion of sucrose. In making fondant with cream of tartar, if the sirup is boiled slowly for a long time, more inversion takes place than if the sirup is boiled quickly. Hydrolysis of fondant containing cream of tartar also occurs during storage though the rate is slow. Fondant made with cream of tartar and stored in a fairly tight container becomes softer than fondant made without the addition of cream of tartar. The amount of the acid salt necessary to bring about this softening at room temperature imparts a slightly sour taste to the fondant, which, to many people, improves the flavor. In fondant made with a larger amount of cream of tartar (Experiment 5C, 4), considerable hydrolysis may occur with short storage.

Hydrolysis in chocolate creams. The fondant centers of chocolate creams, according to Paine (37), must be firm to withstand handling. Their liquefaction is brought about by the enzyme invertase after they are enrobed in the chocolate coating. The invertase is added to the fondant when it is melted for molding. The fondant contains some moisture, the evaporation of which is prevented by the chocolate coating. Moisture is necessary to dissolve the invertase and for hydrolysis. As some sucrose is inverted, the liquid can dissolve more sugar; *i.e.,* a given amount of liquid will dissolve a greater quantity of three sugars, levulose, dextrose, and sucrose, than of sucrose alone. With dissolving of the sugars the centers soften. The rate (37) of inversion is determined by (*a*) the time of storage, (*b*) the temperature during storage, (*c*) the strength of the invertase, (*d*) the amount of invertase added, and (*e*) the hydrogen-ion concentration of the liquid. To bring the *p*H to optimum for action of the invertase, citric or tartaric acid is added along with the invertase to the fondant. Invertase is also used for bonbons (36), which dry out more rapidly than chocolate-coated candies, although a small amount of egg white added to fondant lessens the evaporation.

Effect of Alkalies upon Sugar

Strong alkalies, like strong acids, decompose sugars (40). Weak alkalies or salts with alkaline reaction, like $NaHCO_3$, also act upon sugars. Even alkaline salts found in hard water may produce considerable decomposition in some sugars. Of the carbohydrates, those more easily affected by acids are least readily decomposed by alkali, and vice versa. Sucrose is scarcely acted upon by a weak alkali, but maltose and lactose are affected more readily. The degradation of the disaccharides by alkali is preceded by hydrolysis.

The monosaccharides are easily decomposed by even weak alkalies. With weak alkalies many substances are formed; with strong ones the action is so rapid that fewer end products are obtained. An alkali acting upon dextrose produces first a yellow tinge which becomes deeper and finally brown. This decomposition is called caramelization. With only slight caramelization of dextrose the disagreeable flavor may not be very noticeable, but with more decomposition it becomes stronger and more bitter, being characterized by a strong, pungent, acrid after-taste. In sections of the country where the water is very hard, enough decomposition to affect the flavor may be brought about in ordinary cooking. This is more noticeable when the sugar is cooked slowly. The addition of a little lemon juice, vinegar, or the acid salt, cream of tartar, will prevent the discoloration and the change in flavor. In some products this browning or caramelization is an advantage.

Levulose, like dextrose, is unstable in an alkaline solution, decomposing as readily as dextrose, or even more readily, and giving many decomposition products. But in cookery its decomposition by alkalies can be prevented in the same way as that of dextrose. Candy made from honey often has a strong flavor that may be rather disagreeable, owing to decomposition of the dextrose and levulose during cooking. If just enough acid is added to combine with the alkali present, the characteristic flavor of honey is retained.

Hygroscopic Properties and Keeping

Sugars are hygroscopic and tend to absorb moisture. To have a free-flowing sugar with no lumps depends principally upon the storage conditions. Nelson (35) states that white sugars are best stored at relative humidities below 60% and at temperatures below 38°C. White sugar discolors if stored near radiators. Since brown sugars contain about 4% moisture, they are better if stored under damper conditions than white sugar. Nelson suggests a humidity between 60% and 70% and a temperature below 24°C.

The browning reaction (5) may cause discoloration in some sugar products containing amino groups. Browne (5) states that the greatest losses of sugar and sugar products during storage are from the action of microorganisms.

Browne (4) reports that the sugars having the highest absorptive power from a saturated atmosphere are the levulose-containing substances: invert sugar, honey, levulose, and molasses. This suggests that cakes and cookies made with levulose-containing products will not dry out so rapidly as those made with sucrose. This is found to be true. Honey and molasses are used in many family recipes for cookies, particularly the kinds made for holidays, for they can be made in advance of their intended use and they remain moist when stored; in many instances the moisture content seems to increase during storage.

Invert sugar either added to food or formed by inversion during cooking is found in many food products. In the bakery trade it is used to prevent drying and checking.

The Melting Point of the Sugars

When dry sugars are heated a point is reached at which they change from a crystalline to a liquid state. This is called the melting point. Browne (3) states the melting point of sucrose is from 160° to 180°C, varying with the method of preparation of the sucrose. Hill and Kelly (28) give 186°C. At 210°C sucrose (28) loses water and forms caramel. In the presence of moisture, caramelization may begin at much lower temperatures. The melting points of the sugars also vary with their purity and with the form of the sugar.

Maltose, having a lower melting point than sucrose, decomposes more easily by heat.

Dextrose crystallizes as the hydrate, $C_6H_{12}O_6 \cdot H_2O$; that is, one molecule of water is combined with the molecule of dextrose. Its melting point (28) is 86°, whereas that of the anhydrous dextrose is 146°C.

Levulose has a low melting point, both 95° and 104°C having been found in the literature.

Solutions

Since solutions of sugar and other substances are used constantly in cookery processes, it is desirable to know something about the properties of solutions.

A solution is composed of two parts: the solute is the dissolved substance; the solvent is the substance in which the solute is dissolved. A solution is homogeneous, alike in all parts.

A solution may be a gas dissolved in a solid, a gas in metal; a gas in liquid, air in water; a liquid in a liquid, alcohol in water; or a solid in a liquid, sugar in water. It is to the class of solids in liquids that many solutions in cookery belong.

Solubility of Substances in Solutions

The solubility of a substance is expressed as the amount of that substance which will dissolve in a given volume of a specified solvent at a given temperature and pressure. If the solvent is not mentioned it is understood to be water. Solubility is generally expressed as the number of grams of solute that will dissolve in 100 cc of solvent. If the temperature is not stated it is understood to be room temperature or 20–22°C.

Factors determining the solubility. Temperature, the fineness of division and the nature of the solute, and the nature of the solvent determine the solubility to a great extent. Some substances are highly, others only slightly, soluble in water, and still others are insoluble in this solvent. Some substances dissolve best in alcohol, chloroform, ether, or benzene. Some liquids, like alcohol and water, are mutually soluble in all proportions, but there is a limit to the solubility of all crystalline substances.

Fineness of division of the solute. A very finely divided or powdered crystalline solute is more soluble than the same substance in large crystals because of the increased surface energy of the small particles, and so the total number of grams dissolved in 100 cc of solvent will be greater.

Temperature. Sugars and most salts absorb heat when dissolved and are more soluble at higher temperatures. At 0°C, 179 grams of sucrose will dissolve, at 100°C, 487 grams will dissolve, in 100 cc of water. If a salt evolves heat upon solution its solubility is decreased with elevation of temperature. Calcium hydroxide is only half as soluble at 100° as at 20°. Sodium chloride absorbs little heat on solution, and its solubility changes little with temperature. At 0°, 35.6 grams will dissolve; at 100°, about 39 grams.

Addition of other substances. Two forms of the same compound may have different solubilities. Thus anhydrous lactose has one solubility and the hydrated form another. In addition, the alpha and beta forms differ in solubility. Sometimes the addition of another substance, organic or inorganic, to the solution will increase or decrease the solubility of the solute. If, after all the sucrose possible is dissolved, some potassium acetate, sodium chloride, or other salt is added to the solution, more sucrose can be dissolved. This may affect the solubility of sugar in candy making, for it is known that different waters, with different proportions and kinds of minerals, do not always give identical results, with the same sugar, for the same kind of candy.

Saturated solutions. A saturated solution is one that contains all the dissolved solute that the solvent can take up when in contact with undissolved solute. In other words, it is a solution which when placed with excess of the solute at a definite temperature is in equilibrium; *i.e.*, there is neither increase nor decrease in concentration of the solute.

Supersaturated solutions. One should not define a saturated solution as one containing all the solute it can hold, for a supersaturated solution holds more than a saturated one. If water is heated to 70°C and all the sucrose added that can be dissolved by the water at this temperature, one has a saturated solution. If this solution is carefully cooled to 40°C without stirring, more sucrose will be in solution than could have been if the water had not been heated above 40°. This excess beyond saturation is gradually precipitated as the temperature drops, though crystallization may not begin immediately. But some substances, like the sugars, require longer than others for crystallization to commence, unless the solution is stirred or agitated.

The Solubility of the Sugars

To a certain extent, the solubility of the sugars determines their use. It is obvious to one who does a great deal of cooking that a sugar that requires 6 pounds of water to dissolve 1 pound of sugar could not be used for concentrated sugar products like jellies, jams, frostings, or even cakes.

Sucrose. Sucrose has the greatest solubility of the disaccharide sugars. At room temperature about 2 grams of sucrose are soluble in 1 cc of water.

The solubility of sucrose is given in two ways in Table 7, the percentage of sugar in column 2, and the grams of sucrose dissolved in 100 grams of water in column 3. This table is given in the second edition by Browne (3) but not in the third. For brevity, the solubilities at 5°, 15°, etc., have been omitted.

TABLE 7

SOLUBILITY OF SUCROSE IN WATER AT DIFFERENT TEMPERATURES
(*From Browne's "Handbook of Sugar Analysis"*)

Temperature, degrees C	Grams of sucrose in 100 grams of solution, or %	Grams of sucrose dissolved by 100 grams of water	Specific gravity of solution
0	64.18	179.2	1.31490
10	65.58	190.5	1.32353
20	67.09	203.9	1.33272
30	68.70	219.5	1.34273
40	70.42	238.1	1.35353
50	72.25	260.4	1.36515
60	74.18	287.3	1.37755
70	76.22	320.5	1.39083
80	78.36	362.1	1.40493
90	80.61	415.7	1.41996
100	82.87	487.2	1.43594

Maltose. Less than 1 gram of maltose is soluble in 1 cc of water at room temperature. Gillis (18) reports the solubility given in Table 8.

Lactose. The use of lactose in the home is limited because it is not very soluble and lacks sweetness. According to Greenleaf (22), if lactose

TABLE 8

Solubility of Maltose in Water (*Gillis*)

Temperature, degrees C	Grams of maltose in 100 grams of solution, or %	Grams of maltose dissolved by 100 grams of water
0.6	36.1	56.5
21.0	44.1	78.9
29.6	48.0	93.2
34.4	49.6	98.4
49.4	58.3	139.8
59.8	63.7	175.2
74.2	72.3	261.5
96.5	85.1	569.3

is crystallized below 93.5°C the alpha hydrate form is obtained. Above 93.5°C the beta lactose is formed. Beta lactose is about ¼ sweeter than alpha hydrate, and since it dissolves more rapidly it does not leave a sandy sensation in the mouth. Hudson (29) finds that the addition of $CaCl_2$ to a lactose solution increases the solubility of lactose from 28.6 to 29.5 grams per 100 grams of water at 32°C. An analysis of the precipitate shows that crystals are a compound of lactose with $CaCl_2$. The data in Table 9 of solubility of lactose are from Hudson (29).

TABLE 9

Solubility of Lactose in Water (*Hudson*)

Temperature, degrees C	Final Solubility	
	Grams of lactose per 100 grams of solution, or %	Grams of lactose dissolved by 100 grams of water
0	10.6	11.9
15	14.5	16.9
25	17.8	21.6
39	24.0	31.5
49	29.8	42.4
64	39.7	65.8
74	46.3	86.2
89	58.2	139.2

Dextrose. Dextrose and levulose are the only monosaccharide sugars used in cookery to any extent. Combs and Bele (11) give the solubility of "Cerelose" (trade name of a dextrose) as 83.1 grams dissolved by 100 parts of water at 20°C or 49.7% dextrose. At 63°C the percentage of dextrose per 100 grams of solution is 73.7, and the grams dissolved in 100 grams of water is 281.1.

At room temperature about 1 part of dextrose is soluble in 1 part of water by weight. The solubility of dextrose limits its use in cookery to a certain extent, particularly in jellies, jams, and preserves, since jellies average about 60–70 parts of sugar and 30–40 parts of water by weight. Hence, if dextrose is used alone in jelly, it may crystallize.

Levulose. Levulose is more soluble than sucrose. Since it is very soluble it must be present in very large quantities before it can crystallize, and it crystallizes with difficulty. The solubilities of levulose given in Table 10 are from data of Jackson, Silsbee, and Proffitt (30).

TABLE 10

SOLUBILITY OF LEVULOSE (*Jackson, Silsbee, and Proffitt*)

Temperature, degrees C	Grams of levulose in 100 grams of solution, or %	Grams of levulose dissolved by 100 grams of water
20	78.94	374.8
25	80.29	407.3
30	81.64	444.6
35	82.98	487.5
40	84.34	538.5
45	85.64	596.3
50	86.90	663.3
55	88.10	740.3

Properties of Solutions

A solute dissolved in a solvent affects the properties of the solvent, altering certain of its characteristics. The change in these characteristics may be listed as follows: (*a*) the vapor tension is lowered; (*b*) the boiling point is elevated; (*c*) the freezing point is lowered; (*d*) the osmotic pressure is increased.

Vapor tension. Vapor tension may be defined as the vapor or gaseous pressure of a liquid; it depends upon the amount of vapor formed. This gaseous pressure soon reaches a maximum at any given temperature. The maximum pressure at a definite temperature represents the vapor tension of the liquid. Some liquids, like alcohol, evaporate rapidly and have a high vapor tension. Others, like water, evaporate more slowly.

Effect of the solute on vapor tension. When a substance is dissolved in a liquid the vapor tension of the solvent is lowered, *i.e.,* there is less tendency to pass into the vapor state, hence the gaseous pressure is decreased.

In highly concentrated water solutions of some substances, there is a tendency for water to be absorbed from the air. This is particularly true of sugar solutions, when the humidity of the air is high. On damp, rainy days, fondant and similar candies have to be beaten for a longer time to crystallize, unless they are cooked to a little higher temperature so as to obtain a greater concentration.

The fact that solutes lower the vapor pressure, making it harder for the vapor to leave the surface of the liquid, is utilized in the following or similar ways to keep food moist. A covered vessel containing food loses moisture from the food until the air space is saturated with vapor. If the vessel is tight enough, the food does not dry out to an appreciable extent. If two foods are placed in the same container, the one with more sugar will gradually absorb moisture from the other. This is why an apple is often put in a box with a fruit cake, the apple drying up and keeping the cake moist. Cake and unwrapped bread should not be stored together, as the bread will become dry quickly.

The Boiling Point of Water and Solutions

Water standing in an open vessel gradually evaporates. We know that evaporation takes place more rapidly on warm days than on cool ones, and more rapidly from a wide shallow vessel than from a narrow deep one. As the temperature is increased, the rapidity of the motion of the molecules is increased. Therefore a larger number escape from the liquid as the temperature increases, most of them being carried away by air currents.

Saturated vapor. If we cover a vessel of water, leaving an air space between the surface of the liquid and the cover, evaporation takes place for a time just as from an uncovered vessel. But when the vapor cannot be carried away, the air above the liquid soon becomes filled with vapor molecules. Some of them re-enter the liquid. When they are entering the surface of the liquid as rapidly as they are leaving it, the air is said to be saturated and is in equilibrium with the liquid; *i.e.,* the saturation point is reached when the air holds all the vapor possible at that temperature. If the temperature is increased the velocity of the molecules is increased, and they leave the surface of the liquid faster than they enter until equilibrium is again established. If the temperature is reduced, a part of the vapor condenses into the liquid and forms drops of liquid on the sides and cover of the vessel or on the surface of the liquid.

The boiling point. When heat is applied at the bottom of the pan, the vapor forms as bubbles at the bottom of the liquid. The bubbles, being less dense than the liquid, rise toward the surface, but cannot reach it until the pressure within each bubble is just slightly greater than the pressure exerted upon it by the weight of the column of liquid above it, and, in an open pan, the atmospheric pressure on the surface of the liquid. With increasing temperature, the formation of vapor is more rapid, the speed of the molecules increases, and greater pressure is obtained, so that the vapor can escape from the liquid. When the loss of heat from the escaping vapor is equal to the heat received by the liquid, the temperature is constant. This is the boiling point. Another way to define the boiling point is to say that it is the temperature at which the pressure of the saturated vapor within the liquid is just greater than the outside pressure on the surface of the liquid.

The Bureau of Standards defines the boiling point of water as the point at which ebullition is violent. Slow-bubbling water does not register quite as high a temperature as rapidly bubbling water, but in cooking food in water there is no great advantage in having the water boiling violently. The food will cook nearly as rapidly in the slower bubbling water. With gas or electricity it is an economy of fuel to lower the heat when the water begins to boil, unless it is desirable to evaporate the liquid quickly.

The conversion of water from a liquid to a gaseous state requires a certain amount of energy. This energy is expressed in terms of heat. To change a gram of water at 100°C to vapor at 100° requires about 540 calories of heat. If the heat applied to boiling water is increased, the quantity of water changed to vapor in a given time is increased. The temperature of the water cannot be increased because the heat lost by evaporation is equal to the heat received. If the heat is increased, the heat lost by evaporation is increased and the surface of the bubbles is increased enormously beyond the free surface of the liquid to aid evaporation.

Lowering the boiling point. The boiling point of a liquid may be lowered by reducing the pressure on the liquid. This may be done by boiling the liquid in a partial vacuum. The boiling point is also lowered with increased elevation above sea level. The atmospheric pressure is not so great at high altitudes because of the lessened column or depth of air. At sea level the boiling point of water is 100°C. For each 960 feet above sea level the boiling point is decreased 1°C.

Elevation of the boiling point. The boiling point of a liquid can be elevated by increasing the pressure upon it. The pressure of a gas increases as the temperature increases. When vapor is confined, as in a pressure cooker, the boiling point of a liquid in the cooker is elevated. As the temperature is increased, the pressure of the confined vapor on the surface of the liquid is increased. Therefore a higher temperature is required to form great enough pressure in the vapor bubbles within the liquid for them to reach the surface of the liquid. Thus the boiling point is elevated. The higher the temperature of the confined vapor the greater the pressure on the liquid. The greater the pressure on the liquid the higher the boiling point.

The boiling point of solutions. If a soluble substance is added to a liquid, the resulting solution will have a higher boiling point than the liquid itself. Each gram-molecular weight (mole) of a non-ionized substance in a liter of water elevates the boiling point 0.52°C. A gram-molecular weight of a substance is its molecular weight in grams. For example, that of sucrose is 342 grams. The boiling point of a liter of water containing 342 grams of sucrose is elevated 0.52°C. Two moles of sucrose would elevate the boiling point 1.04°C. The boiling point can be elevated as long as the substance added is soluble. When the solution becomes saturated, or the point is reached at which no more can be dissolved, the boiling point is constant for substances that behave normally in solution. If boiling is continued so that the solvent is vaporized, the excess solute beyond saturation is crystallized. This is illustrated in Experiment 1 in the laboratory outline.

Effect of ionized substances on the boiling point. Some substances when dissolved in water are ionized. In a solution of sodium chloride, for example, not only sodium chloride molecules are found but also sodium and chlorine ions.

$$NaCl \rightleftarrows Na^+ + Cl^-$$

The atomic weight of sodium is 23 and that of chlorine is 35. If 58 grams of sodium chloride (a mole) are added to a liter of water, and the sodium chloride is completely ionized, the boiling point will be elevated 1.04°C. The mole of sodium will elevate it 0.52° and the mole of chlorine will elevate it 0.52°. Sometimes a substance that ionizes in solution is not completely ionized. When this happens, the boiling point is elevated according to the degree of ionization.

At high altitudes it is possible to cook foods more rapidly by adding salt to the cooking water. To be very effective this requires such a large quantity of salt that the food becomes too salty. It may be used for potatoes that are not peeled.

Sugar solutions behave abnormally in that they do not reach a constant boiling point. A mole of sucrose (342 grams) measures about 1¾ cups. It can be readily seen by consulting the solubility table of sucrose that its solubility will account for only a partial elevation of the boiling point. Occasionally, in cooking a sucrose solution (Experiment 2A), some of the sucrose crystallizes on the edge of the pan, thermometer, and top of the sirup, as in the salt solution, but this is not the usual result. When the melting point of the sucrose is reached these crystals melt. Temperatures far above the melting point of the sugars can be obtained. However, with the very high temperatures, caramelization or decomposition of the sucrose occurs quite rapidly.

There is no very satisfactory explanation for the abnormal behavior of the sugars. Chemists tell us that one explanation may be that the sugar and water combine chemically giving a new compound with a new boiling point, or the combination of the sugar with the water may give a very concentrated solution, thus elevating the boiling point.

Boiling point of sucrose solutions. Browne (3) lists the boiling point of sucrose solutions as follows.

TABLE 11

Boiling Point of Sucrose Solutions (*Browne*)

Per cent sucrose.....	10	20	30	40	50	60	70	80	90.8
Boiling point........	100.4	100.6	101.0	101.5	102.0	103.0	106.5	112.0	130.0

A 10% solution of sugar is one that contains 10 grams of sugar and 90 grams of water or one having these proportions.

Heat of solution. Some substances that are soluble may liberate heat when they go into solution. The example of mixing water and sulfuric acid is a well-known one. Other substances, instead of giving off heat, cause the temperature to drop when they go into solution. They are said to have a negative heat of solution, and heat is absorbed.

If sugar and water of the same temperature are mixed, the temperature of the solution drops as the sugar is dissolving. Salt and many other substances also absorb heat as they go into solution. When the substances that absorbed heat as they go into solution are crystallized from solution, heat is liberated and the temperature is elevated slightly. This is often noticeable in making fondant or fudge. Frequently the sirup softens so that it is not so viscous and is easier to stir when crystallization starts. As the first crystals formed are not visible, one may think that the sirup is not going to crystallize because of this softening. It is more noticeable with larger amounts of fondant and fudge than with very small ones.

Crystallization

In making icings, frostings, or candy like fondant and fudge, it is necessary to crystallize the sugar solution. For crystallization to occur, nuclei must form in the solution. To these nuclei the material of the solution is added to form crystals. The size of the crystals formed depends on the number of nuclei present and on the speed of crystallization. If many nuclei are present and the crystallization is rapid, the crystals formed will be numerous and small; if the nuclei are few and the rate of crystallization slow, the crystals will be few and will have time to grow to a large size. Both the rate of formation of nuclei and the rate of crystallization are affected by the nature of the crystallizing substance, the concentration, the temperature, agitation, and the impurities in the solution.

Nature of the crystallizing substance. Some substances like salt crystallize readily from water solution. It requires only a very slight supersaturation to start nuclear formation, and all excess salt in the solution beyond the saturation point is precipitated as crystals. Some substances do not form nuclei or crystallize so readily as salt. With sucrose it is often necessary to have a considerable degree of supersaturation before crystallization commences. Sucrose crystallizes more readily than levulose.

Formation of nuclei. Nuclei cannot form and crystallization cannot occur except from a supersaturated solution. The formation of nuclei, that is the uniting of atoms to form nuclei, is influenced by several factors. If a solution is left to stand, a few nuclei may form spontaneously in various places, and from these nuclei crystallization proceeds. When only a few nuclei develop spontaneously in the solution, the crystals grow to large size. The rate of nuclear formation may be favored by specks of dust in the solution. Agitation or stirring of a solution increases the rate of nuclear formation. Instead of spontaneous formation of nuclei, seeding a solution may be used to start crystallization.

Seeding. When crystals of the same material are added to start crystallization the process is called seeding. These crystals serve as nuclei for crystal growth. If the quantity added is large and the size small, the crystals serve as many nuclei in the solution, and the resulting crystals are small. If the quantity of material added is very small, the nuclei formed are few in number and the crystals are large. One may think of all crystals as being large enough to be visible, but many of them are very small, so small in fact that they may float in the air. If crystals (47) are floating in the air there is the possibility that they may serve to seed solutions, and thus start crystallization.

Rate of crystallization. To the nuclei formed in the solution new molecules from the solution are deposited, in a regular order or manner, so that each crystal has a typical shape. One side or face of a crystal may grow more rapidly than another. The rate at which the nuclei grow larger is called the rate of crystallization. This rate may be favored by the concentration of the solution and its temperature; it may be hindered by foreign substances.

Concentration of the solution. A more concentrated solution favors the formation of nuclei. A fondant sirup cooked to 114°C contains less water and is more concentrated than one cooked to 111°C. Thus nuclei form more readily in the one cooked to 114°C. Large, well-shaped crystals form more readily if the degree of supersaturation is not too great. The most favorable temperature for crystal growth in a saturated sucrose solution boiled to 112°C is between 70° and 90°C. Although crystallization occurs in a very short time when the sirup is stirred at these temperatures, the crystals formed are larger than when the sirup is cooled to a lower temperature. See Figs. 4 and 6. Supersaturation and a low temperature are desirable for the development of small crystals. The viscosity of a very supersaturated sirup delays crystal growth.

Temperature at which crystallization occurs. In general, precipitates come down in coarser crystals if crystallized at high temperatures. Sugars follow this general rule. Other things being equal (1), the higher the temperature at which crystal formation occurs, the coarser the crystals.

A drop in temperature favors the formation of nuclei to a certain point. Crystallization is favored in sugar sirups by cooling to a certain temperature, but is hindered by cooling to a lower temperature. Since the viscosity of a saturated sugar solution becomes increasingly greater as the temperature falls below 70°C, crystal formation is also slower as the temperature falls.

Agitation. Stirring a solution favors the formation of nuclei and hinders the depositing of the material of the solution on the nuclei already formed. Hence, crystals in solutions that are stirred do not develop to the size that they do in spontaneous crystallization. Bancroft (1) states, "The mean size of crystals is determined by the total amount of the material crystallizing and number of crystals. The really important thing therefore is the number of nuclei which are formed under any given conditions." If small crystals are desired, then the conditions should be such that many nuclei are formed. Small crystals are obtained in sirups of definite concentration and temperature, if the sirup is stirred until the mass is kneadable. However, if the sirup is stirred for only a short time, some nuclei are formed, but, after agitation is stopped, the formation of new nuclei is not favored and crystal growth is favored. Figure 5 shows crystals from fondant stirred for only a few seconds. The crystals are much larger than those in Fig. 4, which shows crystals from fondant that was stirred until the mass could be kneaded. The same thing is illustrated in Fig. 13, which shows crystals from divinity that would not quite hold its shape but spread when dropped on oil paper. The crystals from the same divinity (Fig. 12) which was stirred until it would hold its shape, but was glossy and not dry in appearance when dropped on oil paper, are small. Divinity with the small crystals is very smooth and velvety on the palate. This emphasizes the importance of stirring candy and icing sirups until practically all the material is crystallized, if small crystals are desired.

Adsorption and impurities in the solution. Freundlich (17) states that "in the vast majority of cases the foreign substance lowers the rate of crystallization." The rate of crystal growth is retarded because of adsorption of the foreign substance by the crystals. If the substance is strongly adsorbed, crystallization may be retarded to such a rate that it is practically abolished, even though the solution is very supersaturated with the crystallizing substance. Since the adsorption prevents crystal growth, if a precipitate is formed in the presence of a substance strongly adsorbed by the precipitate, it will crystallize in a much finer state of subdivision. Sometimes the substance is more strongly adsorbed at one face than at another, so that this face grows more slowly than is customary and thus becomes comparatively larger in relation to other faces. This explains why crystals from pure solutions may have different shapes from those obtained from impure solutions. Speaking of sugar manufacture and crystallization of sucrose, Zitkowski (52) says, "If the content of non-

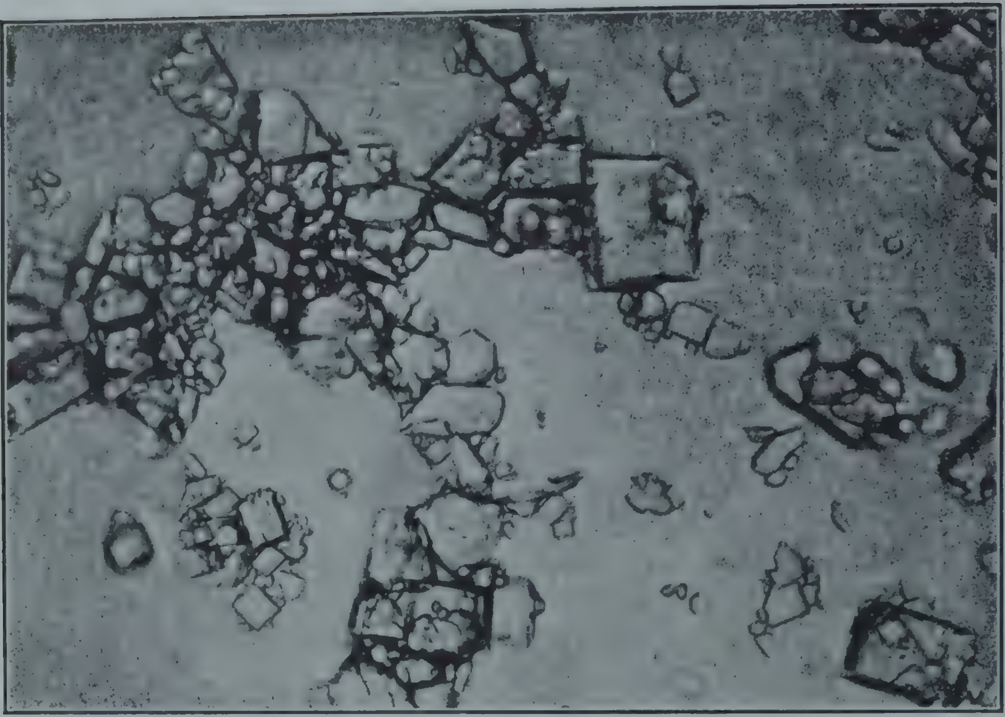
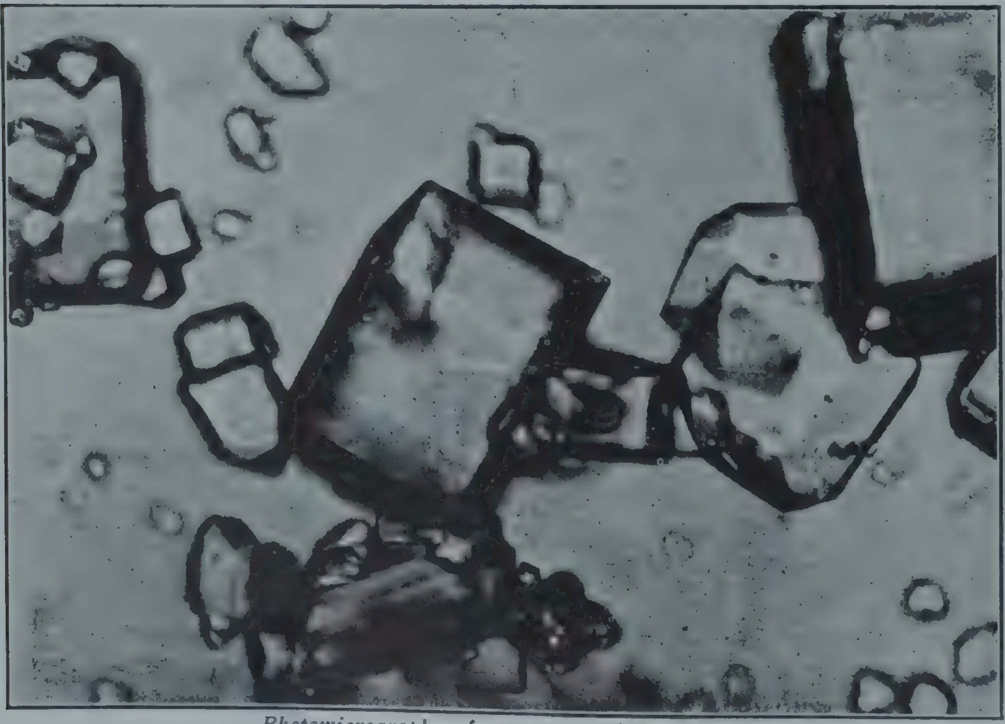


FIG. 4. Crystals from fondant. The sirup was cooked to 113°C—then beaten immediately until the mass was stiff enough to knead. Magnification approximately x 200.



Photomicrographs of sugar crystals by courtesy of Ethel L. Swanson

FIG. 5. Crystals from fondant. A portion of the same sirup as that in Fig. 4. It was beaten slightly while hot to start crystallization; then left to stand several hours until the whole mass was crystallized. Magnification approximately x 200.

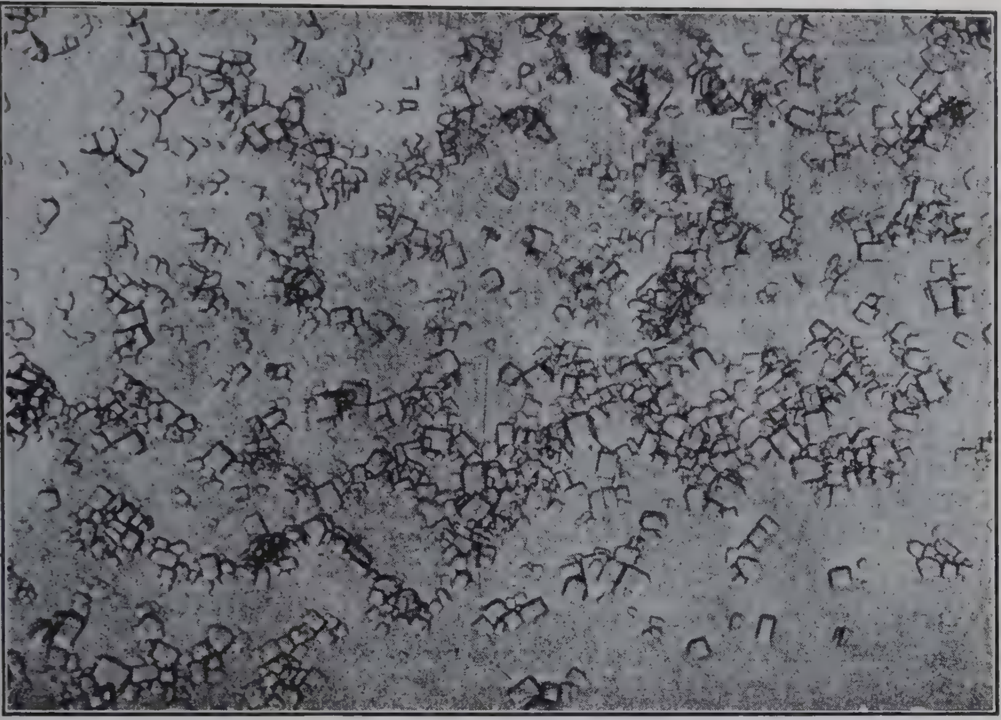


FIG. 6. Crystals from fondant. A portion of the same sirup as that shown in Fig. 4. Cooled to 40°C. Then beaten until the mass was stiff and kneadable. Magnification approximately x 200.

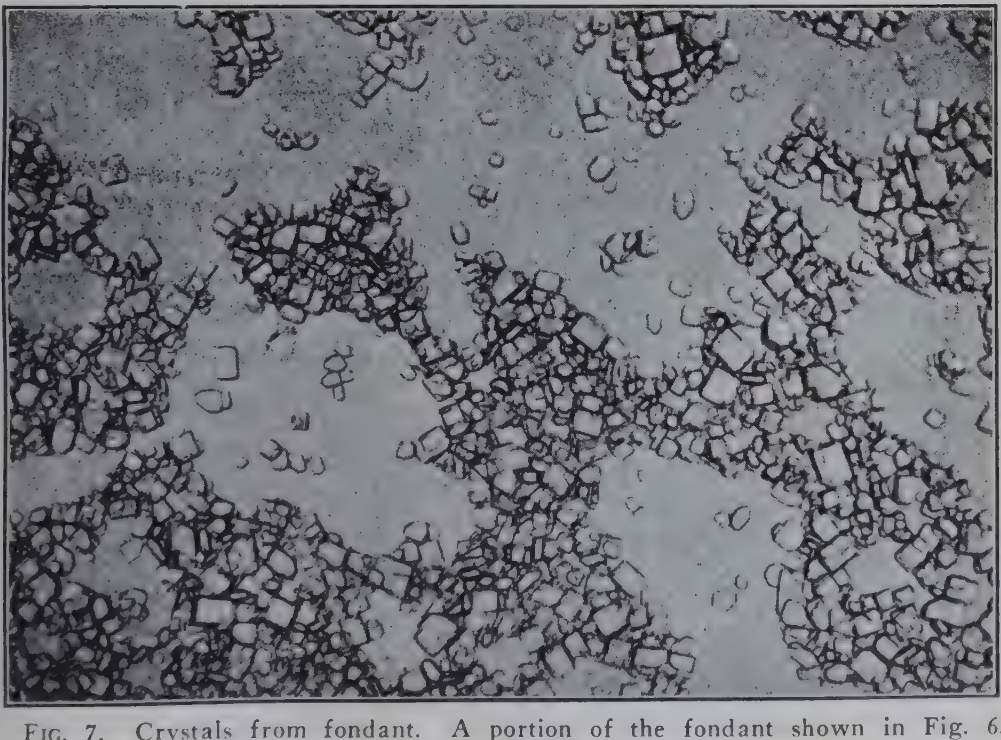


FIG. 7. Crystals from fondant. A portion of the fondant shown in Fig. 6, immediately after adding 6% of beaten egg white. Magnification approximately x 200.

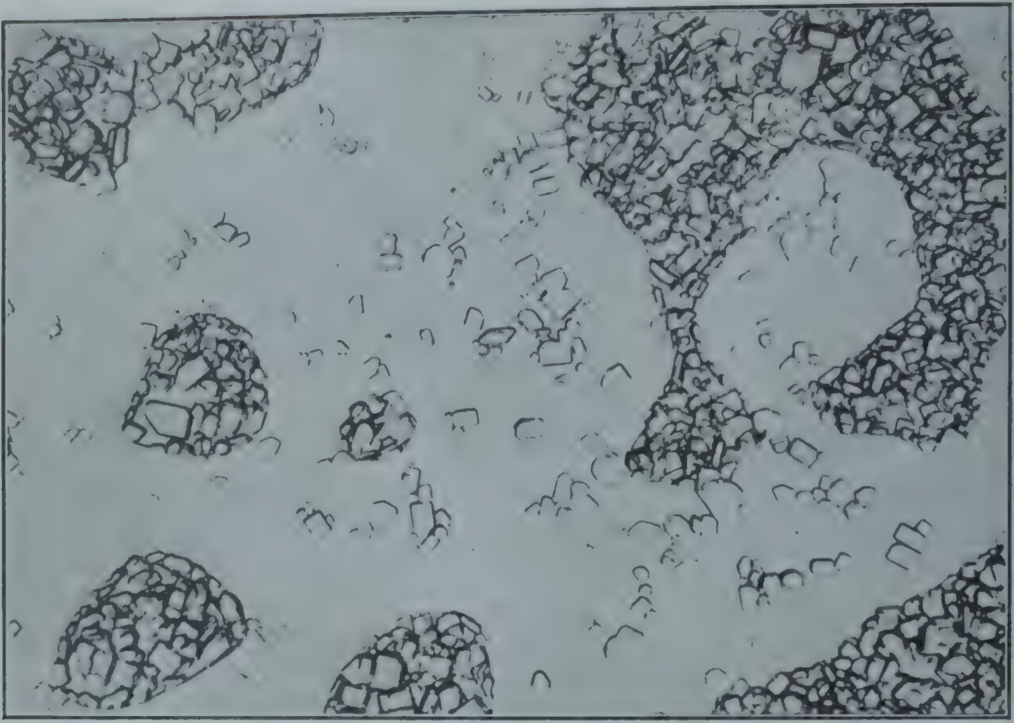


FIG. 8. Crystals from fondant. A portion of the same fondant shown in Fig. 6, after 20 days' storage. Note aggregation of the crystals. Magnification approximately x 200.

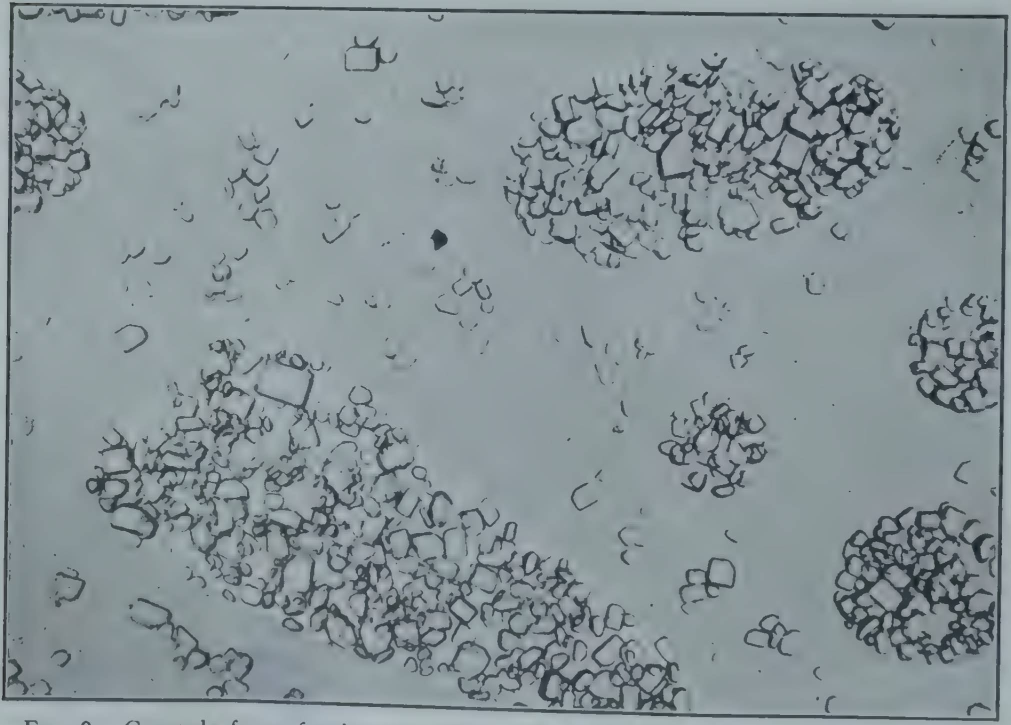


FIG. 9. Crystals from fondant to which 6% egg white was added after 20 days' storage. Compare with Fig. 7. Magnification approximately x 200.

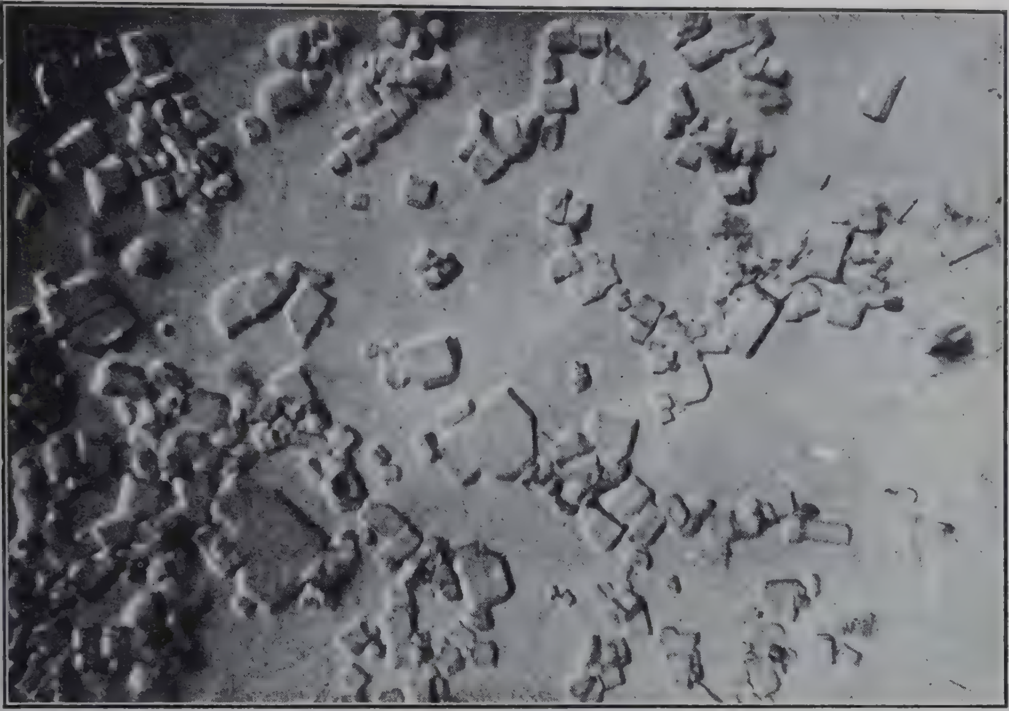


Fig. 10. Crystals from fondant. A portion of the same fondant shown in Fig. 6, after storage for 40 days. Note the growth of crystals. Magnification approximately x 200.

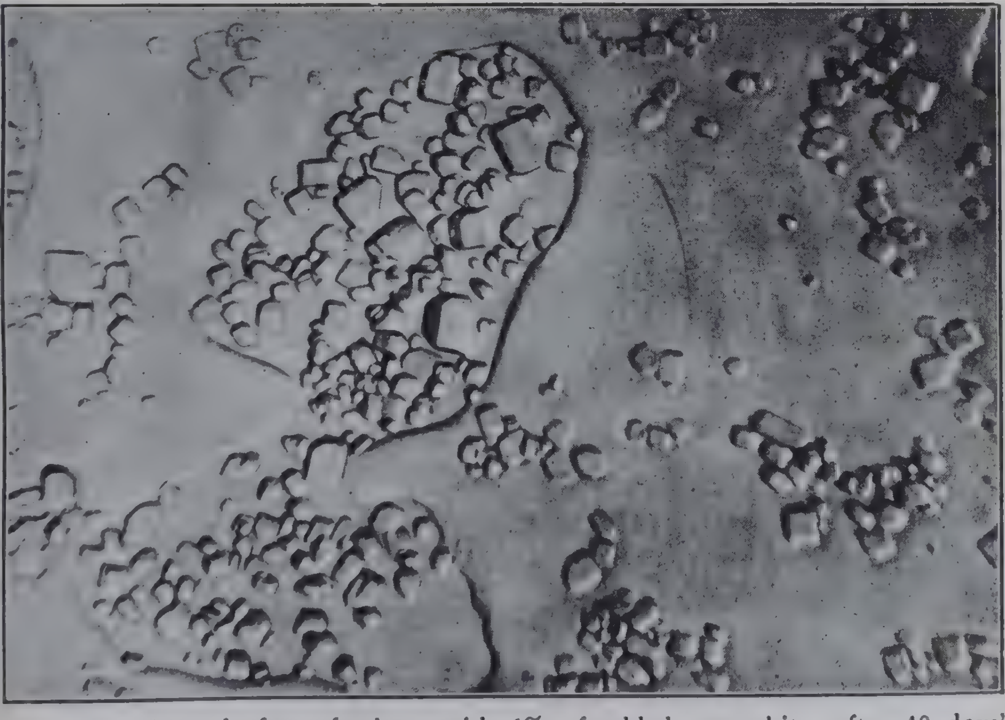


Fig. 11. Crystals from fondant, with 6% of added egg white, after 40 days' storage. A comparison with crystals in Fig. 7 and Fig. 10 shows that egg white tends to retard crystal growth during storage. Magnification approximately x 200.

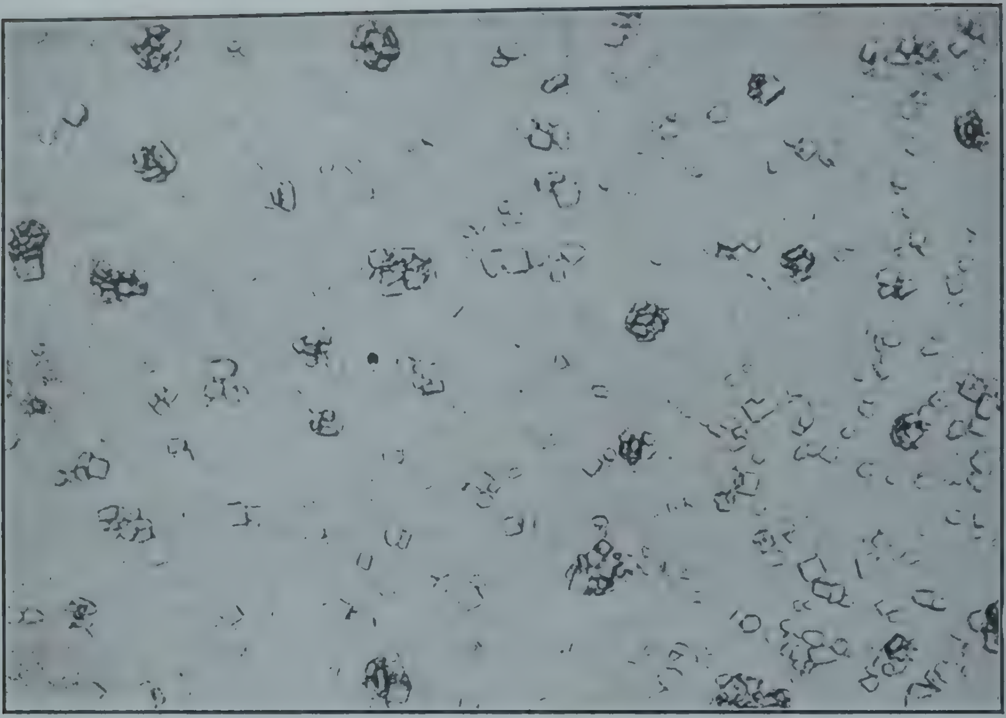


Fig. 12. Crystals from divinity which was beaten until a piece dropped from a spoon would hold its shape, yet still appear glossy. Magnification approximately x 200.

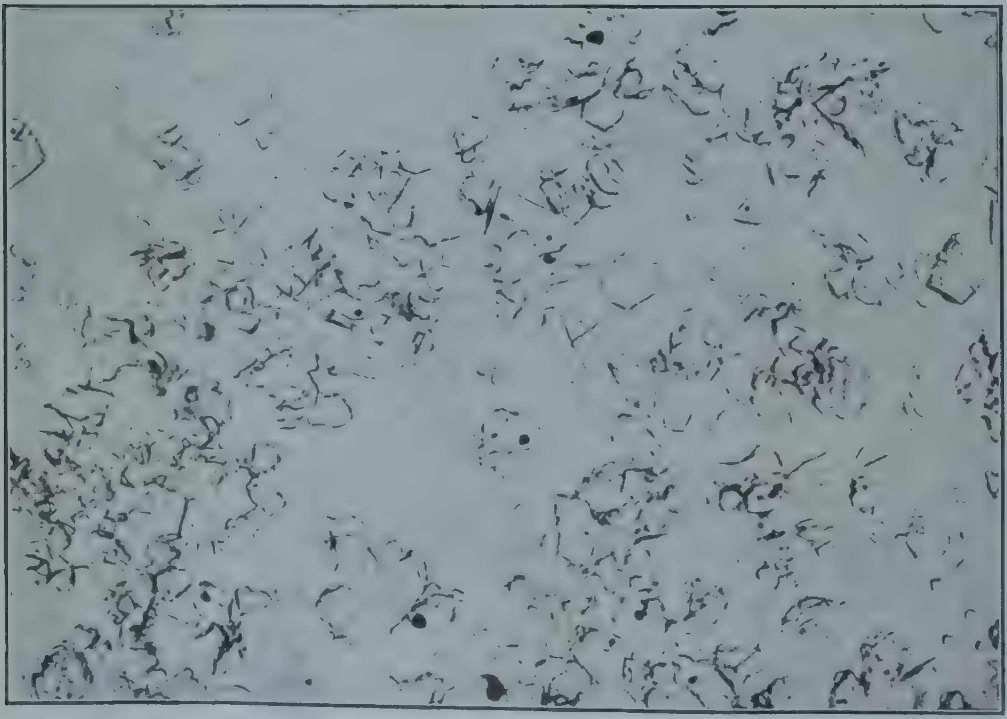


Fig. 13. Crystals from divinity. Some of the same divinity as shown in Fig. 12. But these pieces were not beaten as long as those in Fig. 12. They flattened out when dropped from a spoon. These crystals and those shown in Fig. 5 emphasize the importance of beating candy sufficiently. Magnification approximately x 200.

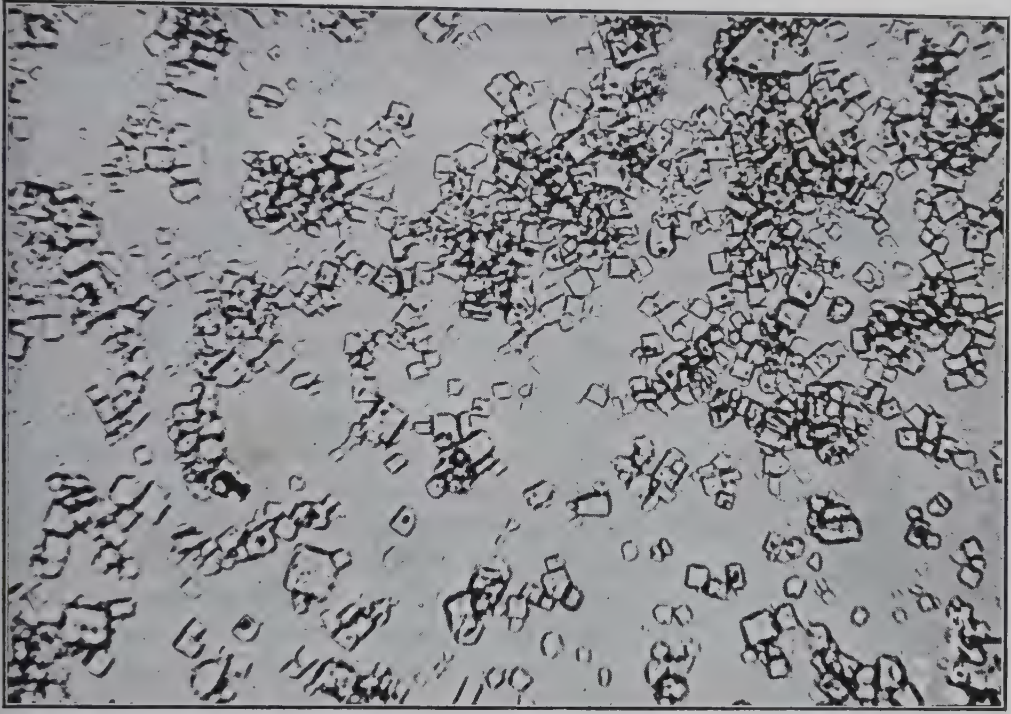


FIG. 14. Crystals from same divinity as shown in Fig. 12, but after 40 days' storage. Compare with crystals in Figs. 10 and 11. Magnification approximately x 200.

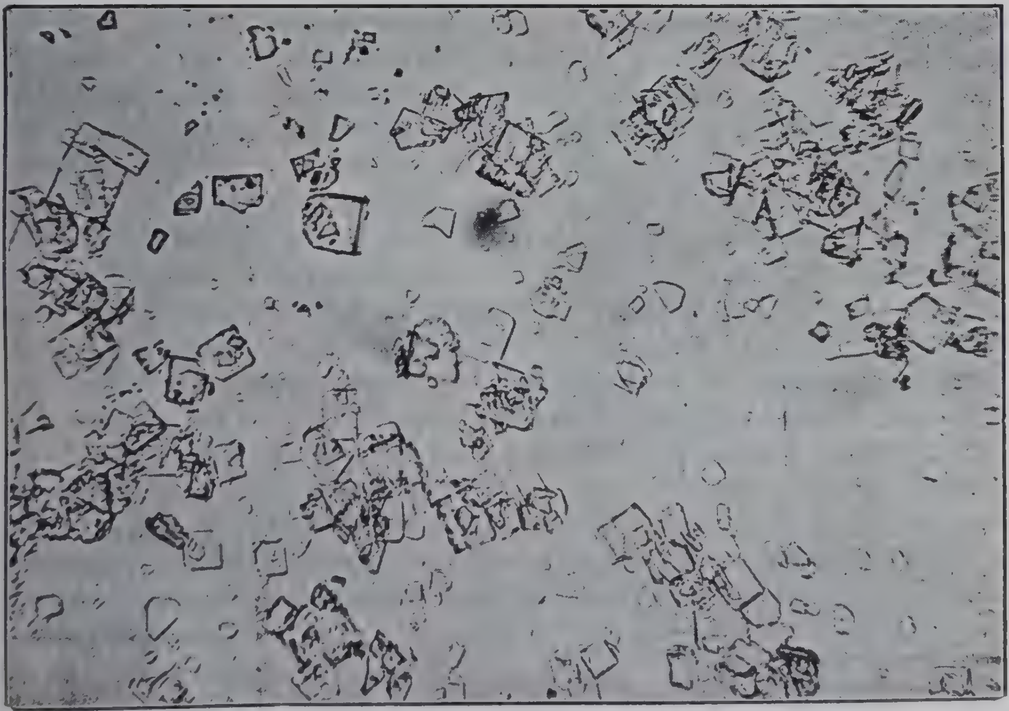


FIG. 15. Corn sirup, sucrose, and water cooked to 119°C and beaten while hot until the mass was stiff. Corn sirup retards crystal growth, see Fig. 4, but not to the same extent that both corn sirup and egg white do. See Fig. 12. Magnification approximately x 200.

sugars in the solution is high enough crystallization may be prevented even though evaporation is carried to the point of dryness." The addition of other carbohydrates, such as dextrose, levulose, and starch, to sucrose solutions retards the crystallization of the sucrose. The extent to which they delay crystallization depends upon how strongly they are adsorbed and the proportion added.

Other substances strongly adsorbed by sucrose crystals are fat and proteins. Hence, the use of butter, milk, or egg white retards crystal growth.

Mixtures of sugars. The rate of crystallization of a mixture of sucrose, dextrose, and levulose is slower than that of sucrose alone, as the mixture has a higher solubility and levulose crystallizes less readily than sucrose. This mixture occurs when sugar is cooked with acid-reacting material, as fondant with cream of tartar, or jellies made with acid fruit juice. Rich preserves made of fruit containing little acid do not crystallize so readily during storage if lemon juice is added when they are being made. The lemon juice brings about more inversion than the less acid fruit juice. The invert sugar does not crystallize so readily as the sucrose, the total quantity of sugar held in solution is greater, and there is less evaporation.

Crystallization of sucrose in sugar manufacture. In sugar manufacture, when it is time to start crystallization in the mass of boiling sirup, the operator may lower the pressure, which causes violent boiling or agitation, or he may add a sirup or water to change the concentration or temperature. He may also seed the sirup by adding a sufficient amount of small sugar crystals. The crystals when first formed are too small to be visible in the sirup but grow to visible size. This may be in a few moments. The temperature, pressure, and density are controlled to bring the crystals to the desired size. If they are too small when finished, too much sugar is lost in washing liquid from the crystals. If they are too large the public does not care for them.

Grades of sugar. Rice (41) states that there is a surprising lack of information about the various grades of sucrose sugar produced and their specific uses, probably because the information has not been given general circulation. He lists 36 grades of sucrose, to which may be added many more grades made for a specific use with a particular equipment. The following classifications are those given by Rice.

The refined sugar distributed for household use is somewhat smaller in grain size than that found some years ago, because the general demand has been for a more rapidly dissolving sugar. As the finer grain gives a whiter appearance, the tendency has been to produce a finer sugar. Fine Granulated is produced in the largest quantity of any grade. In the same class, each with increasingly finer grain or crystal size, are Extra-fine Granulated, Berry or Fruit or Fruit Powdered (it is designated by all these names), and Coating. Rice states that the name Fruit Powdered has nothing to do with fruit nor is the sugar powdered. The "Coating" is used where unusually fine crystals are desired.

Coarse, Standard, Medium, and Manufacturers' Grade are 4 sugars, produced especially for use when high-temperature cooking is necessary in making clear hard candies and very white fondants or pan-coated goods, or when an extremely hard grain must be used. Manufacturers are tending to use Manufacturers' Granulated, which varies from the others only in that it is the finest of the four and will dissolve much faster. In this same class are the Sanding sugars. Sanding sugars are used to sprinkle upon the surfaces of many soft candies and fruit products to prevent their sticking together. They are also used to sand gum drops and fruits which are to have further quantities of sugar crystallized upon their surfaces. The crystals of Sanding sugar are generally nearly perfect and exact in size.

There are generally produced three grades of machine powdered sugar differing only in the degree of fineness: Coarse Powdered, having about the fineness of Coating sugar; Standard Powdered, somewhat finer; and XXXX, commonly known as Confectioners', being as fine as practical to produce with the ordinary type of sugar mill. A still finer powdered sugar, made with an improved powdering mill, is sometimes designated as 6X or Special XXXX. Cold icings prepared from this last sugar remain softer longer than those prepared from coarser powdered sugars. The smaller the particle size the greater the amount of moisture held, because of the proportionally greater surface area. Rice states that the number of X's applied to different sugars means nothing in actual fineness. Powdered sugars may be treated to prevent caking. Usually 3% of cornstarch is added. A tricalcium phosphate has been introduced for this purpose, and 1% of it is more effective than 3% of cornstarch. Its use is not as yet permitted in some states.

Rice describes a new and different sugar called transformed sugar. It is produced in the same way as refined sugar up to the point of crystallization. It is then treated to give a very small grain with exceedingly irregular surface, the surface being penetrated by cracks or recesses which cause the grain to crumble easily, and, because of the relatively large surface, to dissolve almost instantly when dropped into water. The particles may be crushed easily and are used in chocolate coatings. "The crevices in these grains are very small and naturally are full of air. When this sugar is used for creaming with shortening in the production of cake or in very dry dough for biscuits, this finely divided air cannot collect and escape in large bubbles but acts as a leavening agent and reduces the necessity for most, if not all, other leavening agents." Because of its fine and fluffy condition it can replace powdered sugars in various prepared drinks and food mixtures. At present there are seven grades of transformed sugar, varying in fluffiness and color.

Soft brown sugars are graded according to color; they range from a nearly white No. 1 to No. 15, which is as dark as roasted coffee. The grain of these sugars is softer than that of refined sugar and the percentage of invert sugar increases with increasing darkness in color.

Amorphous sugar. When sucrose is melted, or when solutions of sucrose are heated to high temperatures and then allowed to cool, crystallization does not occur immediately. A very brittle, very hard, solid, transparent mass is formed. This form of sucrose is known as amorphous sugar. It crystallizes very slowly, sometimes taking several months or years to crystallize. Candies of this type are extremely hard. Some candies are cooked to stages between those of the soft crystalline ones and the hard amorphous forms. Caramels are examples of this type of candy—they are fairly soft, yet are not crystallized.

Crystallization in confectionery. Crystallization is used in confectionery (25) as a protective coating to prevent moisture loss from gum drops, candied fruits and peels, and similar types of confectionery. Emphasis (25) is laid upon using pure sucrose of high quality with water of little or no mineral content to obtain an even, regular coating of crystals that does not break off readily.

Stages of Cookery of Sucrose Solutions in Candy Making

The "cold-water" test. One can tell, from the firmness or hardness of a portion of the sirup which has been dropped into cold water, whether the sirup has reached a concentration required for the type of candy desired. The degree of firmness in the cold-water test is designated by descriptive terms. But it should be remembered that there is no definite stage between a soft ball and a medium one, for, as the concentration of the solution gradually increases, the firmness of the sirup tested in cold water increases. One factor that causes variations in this test is the fact that the colder the water in which the sirup is tested the firmer the tested portion. Another cause for variation is that the portion being tested is not always left long enough to become cooled.

Yet with long practice the cold-water test can be used with great precision to denote the stage of cookery of a sirup. It is the different interpretations of what constitutes a soft or medium ball that makes this test more difficult to use than a thermometer. The number of terms used by different persons to suggest the same stage of cookery is illustrated by the following. In looking over a large number of recipes for a candy contest, it was interesting to find that of 600 recipes nearly 200 had exactly the same proportion of sugar, corn sirup, water, and egg white. But the directions for making the cold-water test in these 200 recipes varied. Here are some of the terms used to describe the portion of sirup tested in the cold water: soft ball, medium soft ball, medium firm ball, firm ball, hard ball, solid ball, real hard, very hard, hardens, threads, soft crack, crack, crackles, cracks and hops, hairs, spins hairs, strings, snaps, breaks, and brittle.

Stages of cookery. A sucrose sirup that has reached a temperature of 110–112°C does not form a ball when a portion of the sirup is tested in ice water, but spins a 2-inch thread when dropped from a fork or spoon.

At a temperature of 113–115°C a soft ball is formed when a portion of the sirup is tested in ice water. This ball is easily molded in the water, but does not retain its shape at room temperature. Sirup cooked to this stage is used for fondant, fudge, and penuchi.

At 118°C a firmer ball is obtained. At 122°C the ball is still harder and retains its shape at room temperature. Sirups for caramels are cooked to 118–122°C, unless they contain honey or molasses, when a higher temperature is necessary. Temperatures of 118–123°C are used for sucrose sirups that are to be poured over beaten egg white.

The sirup at temperatures of 121–130°C forms an increasingly harder ball, which holds its shape, yet is plastic, when a portion is dropped into ice water; it is used for popcorn balls, nougat, divinity, and some taffies. The sirup at 132–143°, called the soft-crack stage, separates into threads which are hard but not brittle when dropped into ice water. It is used for butterscotch and taffies. Sirups cooked to 149–154°C, the hard-crack stage, separate into threads which are hard and brittle when dropped into cold water; they are used for brittles and glacés.

The length of the thread or hair that forms when a fork or spoon containing some of the sirup is lifted into the air may also serve to indicate the stage of cookery.

Effect upon stage of cookery of addition of corn sirup and other sugars to sucrose solutions. The addition of corn sirups and other sugars to sucrose solutions modifies the firmness of the portion tested at a definite temperature in cold water.

Since the composition of corn sirups varies, different degrees of firmness may result when different corn sirups are used. The use of corn sirup with sucrose in taffy, brittles, or caramels, candies that do not require crystallization, produces a definite stage of hardness when determined by the cold-water test at a lower temperature than when sucrose is used alone. Dextrin is the ingredient of the corn sirup that brings about this result, for if dextrin is used alone with sucrose the temperature for a definite degree of hardness is still lower than when corn sirup is used.

Fondant

Fondant is made when sucrose is cooked with water to a definite temperature, the sirup cooled and beaten, and the mass crystallizes. According to accepted standards, fondant should be snowy white, the crystals so small that they are imperceptible, not gritty on the palate, and the fondant soft enough to be plastic and velvety but not dry and crumbly.

Cooking of fondant. Enough water should be added to dissolve all the sugar during the cooking period. With a slow fire and slow cooking, it is preferable to use less water, or a long time is required for the cooking process. With larger quantities of sugar the proportion of water is reduced because evaporation is slower from the large quantity of sirup than from a small one. Covering the pan during the first part of the cooking period allows the steam to dissolve and wash down crystals from the sides of the pan. A damp cloth is used as a swab to remove crystals formed on the side of the pan during cooking.

The mixture should be stirred to aid in dissolving the sugar, so that no crystals remain in the sirup to start crystallization while it is cooling. Because boiling sugar solutions are not saturated solutions, they may be stirred as much as desired during boiling without causing crystallization, provided that no sirup is splashed on the sides of the pan. However, after the sirup stops boiling it cools quickly and soon reaches the super- or saturation point. If the sirup is poured for cooling from the pan in which it is cooked, it should be done quickly. The portion clinging to the side of the pan should not be scraped with the spoon for this may cause crystals that seed the entire mass. Neither should the thermometer be allowed to roll around in the sirup, for this agitation of the sirup may start premature crystallization. The container in which the fondant is poured to cool should have a smooth surface, as rough surfaces may induce crystallization. It should be level so that all parts of the sirup cool equally.

Concentration and temperature for cooking the sirup. A sucrose solution containing 80% of sucrose, *i.e.*, 80 grams of sucrose and 20 grams of water, boils at 112°C, is saturated at 90°, and supersaturated below 90°C. Hence no crystals are formed in such a sucrose sirup until the temperature drops below 90°C. The higher the temperature to which the sirup is cooked, the less the percentage of water in the fondant. With too small a proportion of water, the fondant is dry and crumbly; with too much it is sirupy and runny. If the sirup is cooked to 109–111°C (Experiment 5B), the fondant contains a high percentage of moisture. Sirups cooked to this temperature give a fondant too fluid to knead or mold unless beaten when hot. Fondant sirup for ordinary home use may be cooked to 113–115°C. The sirup (21) is cooked about 1°C lower for each increase of 900 feet in elevation. Lower temperatures give a softer fondant for remelting and making candy like peppermints; higher temperatures give a drier fondant for molding. Evaporation is proportionally greater from a small quantity of fondant, during stirring and kneading, than from a larger quantity. On rainy or damp days, when the humidity is high, the sirup may absorb moisture from the air, so that it is preferable to cook the sirup to a higher temperature. Jordan (31) states that commercially the amount of moisture in fondant is controlled carefully according to the use for which it is intended, as a difference of 1% of moisture results in a fondant too soft to handle or too dry to knead.

The growth of crystals in fondant. The factors determining the size of crystals in sugar crystallization have been considered. These same factors apply to crystallization in candy making. Freundlich (17) states, "Surface tension is also the cause of recrystallization, in which small crystals unite to larger ones. Probably this phenomenon is similar to the union of minute droplets to large ones, when in direct contact." Water in fondant is a saturated sucrose solution. Owing to the higher surface energy of small crystals, as discussed in Chapter 1, the smaller crystals dissolve, and the larger crystals increase in size.

Crystals (23) in fondant grow in size during storage. The growth of crystals in fondant after 40 days' storage is shown in Figs. 5–11. Compare these crystals with those shown in Fig. 6.

The addition of egg white to fondant. The addition of beaten egg white to fondant retards the rate of crystal growth during storage. Figures 7, 9, and 11 show crystals from fondant to which egg white has been added. Since the egg white is adsorbed by the crystals, its effectiveness in preventing crystal growth may partially depend upon how it is distributed throughout the fondant. Swanson (46) found that not much more than 6% of beaten egg white can be added to fondant without making it too fluid. She found 3% of added egg white as effective as 6% in preventing growth of crystals during storage.

The addition of dextrose, levulose, or invert sugar to fondant. Dextrose, levulose, or invert sirup may be added directly to sucrose solutions to aid in regulating the size of the crystals, or invert sugar may be formed during cooking of the sucrose solution by adding citric, tartaric, or acetic acid, or cream of tartar. It is difficult to regulate conditions, such as the time of cooking, to obtain a definite percentage of invert sugar in the cooked product, for sucrose is inverted more rapidly with higher temperatures, with longer time at high temperatures, and with greater acidity. Hence it is sometimes preferable to add a definite quantity of dextrose, levulose, or invert sugar. Hamaguti et al. (24) give the following ranking for increasing hydrolytic power of organic acids on 60% sucrose solution at 50°C: acetic < malic < fumaric < formic < tartaric < citric < malonic < maleic < oxalic. Woodruff and van Gilder (51) find that cream of tartar inverts the sucrose more slowly than citric, tartaric, or hydrochloric acids at the same *p*H. Cream of tartar can be added in sufficient quantity to produce enough invert sugar to give small crystals and to add to the smoothness of the fondant. If added in too large a quantity, too much invert sugar is formed, so that the fondant is too fluid, and the flavor of the fondant is quite acid.

The larger the quantity of dextrose or levulose added in making fondant, the longer the time required to beat the sirup to bring about crystallization. With an excess of these sugars the fondant is soft.

Woodruff and van Gilder (51) state that sirups containing concentrations of 43% or more invert sugar will not crystallize; those containing 16–23% form a semifluid mass of crystals; those with 6–15% give a plastic, moldable product. With 11.1% or more of invert sugar the crystals of maximum size measure 10 to 13.2 microns, and the grain is exceedingly fine to tongue and roof of the mouth. Fondants containing 7% reducing sugars of either kind (glucose or levulose) are of agreeably fine texture, their largest crystals measuring 15–19 microns. Crystals in candies of observed coarse texture measure 45 microns or more. Differences in crystal size of 6 to 10 microns, which was the difference of crystal measurements of fondants rated very fine and slightly coarse, could be detected by the tactile sense.

The addition of corn sirup (23), which contains dextrose and dextrin, tends to prevent the growth of crystals during storage of fondant (Figs. 12–15). Cream of tartar also retards crystal growth.

Color of fondant. Fondant crystallized without stirring is not snowy white but more transparent. The snow-white appearance is due to the small air particles incorporated during agitation. Egg white may be added to fondant. Paine (36) states that the addition of a small quantity of egg white prevents the aggregation of the air particles, aiding in keeping the fondant white. The beaten egg also incorporates additional air.

Fondant made with hard water, *p*H 7.2 to 7.8, has a creamy tint. This may be caused by slight traces of flavones in the sugar but is probably due to caramelization or some other cause. If, to some of the same sugar and water, a little cream of tartar is added, a snowy white fondant is always obtained. If, however, corn sirup is added to the sugar to make fondant with the above water a gray color develops. The color is so pronounced that the fondant is not attractive looking. If distilled water is used with the corn sirup and sucrose, the gray color does not develop.

Ripening. When fondant stands 12–24 hours it seems more moist, is more plastic, and kneads more easily than when it was first made. In the candy trade this is known as "ripening." Fondants that contain substances that cause slow hydrolysis of the sucrose become softer on account of the formation of invert sugar, but "ripening" is an additional process and occurs in fondant containing only sucrose. Carrick (9) suggests that the reason for this "ripening" is that the small crystals in the mass are dissolved, thus letting the large crystals move more easily, and they are thus more plastic.

Honey fondant. Candies made from pure honey, on account of the high levulose content and moisture-absorbing property of honey, usually become very sticky a few hours after they are made. Phillips (39) reports Stratton's (44) combination of honey, whole milk, and lactose sugar to make fondant. Fondant usually contains some crystals of each of the sugars that enter into its composition, but in this instance the crystal phase is entirely lactose, the crystals being particularly minute. But the lactose crystals have a tendency to grow so that fondants smooth at first become somewhat grainy. However, honey fondant will absorb a relatively high percentage of whole milk by mechanical mixing, and this milk tends to prevent the growth of lactose crystals. The honey has an unusual preservative action, for the milk in the mixture remains sweet as long as the candy is kept.

Fudge

The same factors control the size of the crystals in fondant making and in fudge. Fudge is often made of brown sugar. As brown sugar contains a higher percentage of invert sugar than granulated sugar, it crystallizes less readily.

Fudge also ripens with storage and if placed in a container with a tight-fitting lid becomes much softer and more velvety after 24 hours' storage.

In substituting cocoa for the chocolate in fudge, Reese (45) found that the quantity of cocoa was a matter of individual preference, although 3–3.5 tablespoons to each cup of sugar was preferred by the majority of judges. But, if other conditions were standardized, the final temperature to which the sirup was cooked depended upon the proportion of cocoa used. Cocoa contains considerable dextrin. It is probably the presence of this ingredient that affects the consistency of the sirup so that with increasing amounts of cocoa the temperature to which the sirup is cooked should be lower. For a sirup cooled to 40°C and requiring about 12–15 minutes to beat to bring about crystallization, the fudge containing 1 tablespoon of cocoa is cooked to 112.5° or 113°C. For each additional tablespoon of cocoa the temperature to which the sirup is cooked can be lowered one-half degree. These conditions hold for the recipe given in the laboratory outline. With larger proportions of butter, the temperature to which the sirup is cooked should be elevated.

Caramels

Caramels, taffy, and brittles are types of candy that are firm but not crystallized. To prevent crystallization larger quantities of dextrose, levulose, corn sirup, or other substances are added than when making fondant or fudge. If these substances are not added directly, then larger quantities of substances that produce inversion of sucrose are used, thus giving a higher percentage of invert sugar.

Corn sirup and molasses are the materials most commonly used in caramels to prevent crystallization. The temperature to which caramels are cooked depends upon the ingredients and their proportion. With increasing amounts of corn sirup, because of its dextrin content, the temperature to which the caramels are cooked is lowered. But with molasses or honey the temperature to which the caramels are cooked is much higher than when corn sirup is used. In the recipe given in the experimental outline with 1 cup of corn sirup to 2 cups of sucrose, a temperature of 119–120°C produces the degree of firmness liked by most people. If the corn sirup is increased to 2 cups and the sucrose reduced to 1 cup the same firmness is produced by cooking to 116–117°C. If dextrose, honey, or molasses is substituted for the corn sirup, the temperature to which the sirup must be cooked to give the same firmness is above 120°, sometimes as much as 126°C or higher, depending on the type of molasses or the proportion used.

The amount of milk in caramels. A large quantity of milk in caramels develops a flavor that can be obtained in no other way. Slow cooking develops more of the brown color and flavor than rapid cooking. The color comes from lactose-protein and dextrose-protein compounds and the caramelization of the lactose with high temperatures and long cooking.

If all the milk is added when cooking is first started the milk may curdle. If most of the milk is added slowly after the sirup is thick it very seldom curdles. In using large quantities of milk in caramels the protein of the milk will tend to prevent crystallization.

Large quantities of fat increase the richness of caramels.

Caramels are stirred or handled as little as possible after the sirup stops boiling until they are cool. After the boiling is stopped they soon reach the saturation point, which for caramels is above 100°C, and stirring the sirup or scraping the pan tends to produce crystals.

Taffy

Taffies or pulled candies have vinegar, lemon juice, or cream of tartar added during cooking. These substances cause inversion of the sucrose, which prevents crystallization. Dextrose, corn sirup, or molasses may be added to the sucrose to prevent crystallization. Pulled taffies become white, or if made with molasses become much lighter in color, on account of the air bubbles incorporated during pulling.

The cooking temperatures of pulled candies vary according to the ingredients and their proportions, but follow the same general rules as for caramels. Those containing large quantities of corn sirup are cooked to lower temperatures. Taffies are firmer than caramels and are therefore cooked to higher temperatures.

Brittles

Brittles are much harder than caramels or taffies and are cooked to high temperatures. At the temperatures to which they are cooked carameli-zation of the sugar may take place, and this as well as added substances tends to prevent crystallization. If caramelization is very extensive, a number of decomposition products of sugar may develop, among which are some acid substances. The greater the amount of carmelization the stronger the flavor developed. Soda is often added to brittles. It not only neutralizes the acidity developed and lessens the bitter flavor but owing to gas formed gives a porous texture to the brittle.

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SUGAR COOKERY

Laboratory Outline

Keep a record of the experiments performed in a permanent notebook. The experiments should be written up under the following headings. The object of the experiment, what happens, the results, and, most important, the conclusion drawn or the application of the results in preparation of food. Suggestive headings for record of what happens may be used for most of the experiments.

Experiment 1.

To determine the effect on the boiling point of water when a soluble substance is added.

Determine the boiling point of water in your laboratory. Then to 1 cup of water add a scant ¼ cup of salt. Heat to the boiling point. Note the temperature. Continue boiling. Does the temperature change? Continue boiling until the temperature remains constant. What other change occurs? What is the effect on the boiling point when salt is added to water?

Experiment 2.

To determine the boiling temperature of sugar sirups corresponding to the "cold-water tests" used in candy making.

A. Sucrose sirup.

Dissolve 1 cup of sucrose (granulated sugar) in ½ cup of water. (The proportion of sugar and water used may need to be increased. The quantity of sirup should be sufficient to cover the thermometer stem to a depth of ½ inch above the bulb. The amount of sugar needed depends upon the size of the pan and the length of the thermometer bulb.) Bring the solution to boiling. Note rise in temperature with constant boiling. Explain. Why can a higher temperature be obtained with the sugar solution than with the salt solution?

Cook the sirup in sauce pans of the same size and shape. At the temperatures given below remove portions of the sirup. Remove the pan from the stove when making each test. Drop a tablespoon of the sirup in cold water. Note the consistency. Is it easily molded? Does it ring when hit against the side of the container? When do threads or hairs begin to form when a portion of the sirup is allowed to flow from a spoon? How do the character and length of the threads vary at different temperatures? Keep the series of tests on your work tray for comparison with the following experiments and with your neighbors' results. Note the texture at room temperature. Is it soft, firm, or brittle? Put a portion in your mouth. Does it dissolve rapidly on the tongue? To what stage in candy cookery does each of the temperatures given correspond?

Remove portions of the sirup at 111°, 113°, 118°, 122°, 132°, 145°, and 170°C (231.8°, 236.4°, 244.4°, 251.2°, 269.2°, 293°, and 338°F). Compare with results given in candy and in cook books. Tabulate your results.

B. Sucrose and corn sirup.

Dissolve ½ cup (100 grams) of sucrose and ½ cup (162 grams) of commercial corn sirup in ⅓ cup of water. Repeat directions under A2. What is the effect on the stage of cookery or hardness when one-half sucrose and one-half corn sirup are used? Compare your results with those of Miss Daniels in *J. Home Ecpn. 6:* 457 and 482 (1914).

C. Sucrose and crystalline dextrose.

Dissolve ½ cup (100 grams) of sucrose and ½ cup of crystalline dextrose (80 grams) in ½ cup of water. Repeat directions under A2. How does the hardness of the sirups obtained under A2, B2, and C2 compare for any given definite temperature, for example, 118°C?

D. Sucrose and dextrin.

Dissolve ½ cup (100 grams) of sucrose and ½ cup of dextrin in ½ cup of water. Repeat directions under A2.

E. Variations.

1. Repeat Experiment C2, using one-half sucrose and one-half sorghum. Repeat, using molasses for the sorghum.

2. Repeat B2, using 2 parts of sucrose to 1 part of corn sirup. Repeat using dextrose for the corn sirup.

3. Repeat B2, using 1 part of sucrose and 2 parts of corn sirup. Repeat using dextrose for the corn sirup.

Taffy

Experiment 3.

To determine the conditions necessary for making a pulled candy.

Recipe:

Sugar	1 cup	200 grams
Water	½ cup	

Directions. Combine the ingredients. Cover the pan for the first few minutes of boiling. Why? Cook to the desired temperature and pour quickly into a buttered plate. Do not scrape the cooking pan with the spoon. Cool the sirup until it can be handled without burning the hands. Pull until light in color.

1. Cook to 128°C (262.8°F).
2. To the above recipe add 1 teaspoon of cream of tartar.
3. To the recipe add ¼ cup (81 grams) of corn sirup. Should the temperature to which the sirup is cooked be higher or lower than 128°C?
4. To the recipe add ½ cup (162 grams) of corn sirup. Should the temperature to which the sirup is cooked be higher or lower than 128°C?
5. To the recipe add 1½ tablespoons of vinegar.
6. To the recipe add ½ cup (162 grams) of sorghum or molasses. To what temperature should the sirup be cooked?
7. To the recipe add ½ cup of honey (162 grams). To what temperature should the sirup be cooked?

Is 128°C always the best temperature for pulled candies? Look up recipes in cook books. What do they contain besides sugar and a liquid? What is the purpose of the added substances? When the candy has hardened examine a portion under the microscope. Is the candy crystallized? Save portions of all candies for several days. Do any crystallize after long standing? Compare the behavior of this candy with that of sulfur in the crystalline and the amorphous condition.

Enumerate all the factors which may cause the relationship between the cold-water test and a given boiling temperature to vary. What would the results be if 1 or 2 tablespoons of lemon juice were added to the pulled candy recipe?

Caramels

Experiment 4.

To determine the conditions necessary for making caramels.

Recipe:

Sugar	2 cups	400 grams
Corn sirup	1 cup	328 grams
Butter	2 tablespoons	28 grams
Milk	3 cups	732 grams

Prepare one-quarter or one-half of the recipe.

1. Combine all the ingredients and stir while cooking to prevent scorching. Cook to 121°C (249.8°F), and turn into a buttered pan very quickly, taking care not to scrape the contents of the cooking pan with the spoon while pouring the caramel mixture. Do not try to drain the last of the contents of the

cooking pan into the cooling pan. When cool enough, cut into squares with scissors or a knife.

2. Combine all the ingredients but reserve two-thirds of the milk. Cook until quite thick, about 119°C (246.2°F), then add half of the remaining milk so slowly that the mixture does not stop boiling. Cook until the sirup becomes thick again; then add the remainder of the milk slowly. When the temperature reaches 121°C (249.8°F) remove from the fire and follow directions under 1.

3. Repeat 2, but cook to 119°C.

4. Repeat 2, but use 1½ cups of sugar and 1½ cups of corn sirup. Cook to 118°C (244.4°F).

5. Follow directions under 2 for combining but use 1 cup of sugar and 2 cups of corn sirup. Cook to 116–117°C (240.8–242.6°F).

6. Substitute 1 cup of sorghum for the corn sirup. To what temperature does it need to be cooked to have the cold-water test the same firmness as in 3? Follow directions under 2 for combining and cook so that the caramels will be as firm as those under 3.

7. Repeat 6 but substitute strained honey for the sorghum.

8. Substitute 2 cups of cream for the 3 cups of milk. Omit the butter. Follow directions under 2 for combining. Add ⅛ teaspoon salt. Cook to 119°C (246.2°F).

9. Reduce the milk to 2 cups and increase the butter to ½ cup. Follow directions under 2. Cook to 119°C.

10. Substitute ¾ cup of evaporated milk for the 3 cups of milk. Follow directions under 1. Cook to 119°C.

11. Substitute 1 cup of water for the 3 cups of milk. Follow directions under 1 for combining. Cook to 119°C.

12. Add 2 squares of chocolate (56 grams) to the recipe. Follow directions under 2 for combining. Cook to 119°C.

Cold-water test for caramels. The caramels are cooked sufficiently when a portion of the sirup dropped in cold water is as firm as that wished in the finished caramel. If small quantities of ingredients are used in making caramels, it is difficult to use a thermometer for the stirring of the viscous sirup pulls and piles it up against the thermometer. The viscosity of the solution also seems to have a tendency to hold in for a few seconds some of the steam formed. Thus it is difficult to secure accurate readings, the temperature fluctuating considerably.

Wrap portions of each of the caramels and store until the following class period. Do any of them crystallize? Do those with the larger proportions of corn sirup keep better? Do any with the small proportions of corn sirup crystallize? When the proportions of the ingredients of the recipe are changed is the temperature as indicated by the thermometer or the cold-water test a better indication that the sirup is the right concentration for removing from the fire? Can smaller quantities of milk be used?

Fondant

Experiment 5.

To determine the factors which influence the rate of crystallization of sucrose and the size of the crystals.

Dissolve 1 cup of sucrose (200 grams) in ½ cup of water. (Increase or decrease these proportions if necessary.) Use pans of the same size and shape. Be sure the pans are smooth. Because the sirup splashed on the sides dries less readily from the heat of the burner, a pan with a straight side or one that curves in at the top is preferable to one that slopes outward at the top. If desired the sirup may be poured into plates for cooling instead of following directions under the outline. If this is done the containers into which it is poured should be smooth and the same size and all should be cooled in the same manner. Great care should also be taken to pour the sirup rapidly and not to scrape the pan.

If the amount of water in the fondant is to be determined, the pan and the stirring spoon should be weighed before the fondant is cooked. The weight of the fondant, before removal from the cooking pan, minus the weight of the sugar used gives the amount of water in the fondant.

A. Temperature at which the sirup is beaten.

1. Cook the sirup covered for 4 or 5 minutes. Remove the lid and continue boiling until sufficiently concentrated. (Cook to 113°C [236.4°F] if the day is clear, and to 114° or 115°C [238.2° or 239°F] if rainy or if the humidity is high.)

Boil the sirup without stirring or if stirred follow the caution given in the text. Cool the sirup in the sauce pan to 40°C (104°F), then beat until stiff. A wooden spoon for beating is less likely to form blisters on the hands than a metal spoon. After crystallization has occurred, knead until soft. Care should be taken that no crystals form on the side of the pan during cooking or cooling, for they will seed the mass and the time for beating will thus be shorter for A2 and A3 than would normally be required and the crystals larger.

2. Repeat 1, but cool only to 70°C (158°F) before beating.

3. Repeat 1, but beat the sirup as soon as it is removed from the stove.

Examine portions of each fondant under the microscope. Wrap portions from each experiment in oiled paper and put away in a tightly covered container until the next lesson. What is the effect of 24 hours' storage on the firmness and the texture of the fondant? Why do the directions under A1 state not to stir the sirup while cooking?

B. Concentration to which the sirup is cooked.

Repeat A1, but cook the sirup to 111°C (231.8°F). Compare the length of time required to beat to crystallize with that for A3.

C. Effect of added substances.

1. Repeat A1, but add 1 tablespoon of butter to the sugar and water. Follow directions under A1.

2. Repeat A1, but add ¼ teaspoon of cream of tartar to the recipe. The proportion of cream of tartar may need to be varied somewhat with the hardness of the water, but the rate of cooking will have more effect than the hardness of the water. Boil over a large gas burner so that the time of cooking does not exceed 10 to 12 minutes. Follow directions under A1.

3. Repeat C2, but cook slowly, taking at least 2 or 3 times as long to cook as for C2.

4. Repeat A1, but add 1 teaspoon of cream of tartar to the recipe.

5. Repeat A1, adding 1 tablespoon of corn sirup to the recipe.

6. Repeat A1, adding 4 tablespoons of corn sirup to the recipe.

7. Melt 4 tablespoons of sugar. Stir while melting. Do not have the heat intense enough to decidedly darken or scorch the sirup. When it is all melted and a golden brown color, add boiling water and stir until dissolved. Then add to the fondant recipe, and follow directions under C1.

If C4, 6, and 7 do not crystallize let them stand until the next lesson. What would be the effect on the rate of crystallization if these candies were allowed to cook to a higher temperature? If they were beaten hot? What is the effect on the rate of crystallization of sugar when considerable hydrolysis has occurred, as in C3 and C4, or when a large amount of corn sirup or caramelized sugar has been added, as in C6 or C7?

Test portions of A1 and C2 with Fehling's solution.

What is the action of cream of tartar when added to fondant? What would be the result if vinegar or lemon juice were substituted for the cream of tartar in C2 and C3? Is the fondant obtained in C2 and C3 superior to that obtained in A1? Compare the keeping qualities of the different fondants by putting some of each away in a covered container and observing at different periods. Examine portions of each under the microscope.

Fudge

Experiment 6.

To determine the factors influencing the consistency and flavor of fudge.

Recipe:

Sugar	1 cup	200 grams
Milk	½ cup	122 grams
Butter	1 tablespoon	14 grams
Chocolate	¾ square	21 grams

Combine sugar, chocolate, butter, and liquid. Stir until the sugar is dissolved and the chocolate is melted. Cook to the temperatures given below. If the mixture is poured into another container for cooling, be sure the container is smooth. If it is poured into a platter or similar utensil, cooling will be more rapid and even more so if the platter is set on a cake rack or is elevated. Use containers of the same size and the same method for all the experiments. Cool to 40°C, and beat until the mass begins to crystallize. Turn quickly into a buttered pan or knead as desired. Select thermometers that have the same boiling point. The recipe may need to be doubled or increased so that the quantity of material in the cooking pan will be great enough to cover the bulb of the thermometer in order to obtain an accurate reading. How should the thermometers be held in the sirup to determine differences in consistency of the finished fudge, when the difference in temperature to which the sirup is cooked is only 1 degree?

Compare the texture and consistency of each fudge. What temperature is most desirable for fudge that is not kneaded? For fudge that is kneaded? If granular fudge is desired and the sirup is stirred while hot, should the sirup be cooked to the same degree as for fudge that is beaten after cooling? In making 4 times the recipe would you take 4 times the quantity of liquid? Why?

A. Temperature to which the sirup is cooked.

1. Cook to 110°C (230°F).

2. Cook to 111°C (231.8°F).
3. Cook to 112°C (234.6°F).
4. Cook to 113°C (236.4°F).
5. Cook to 115°C (239°F).

B. Kind of liquid.

Cook to the temperature found best under A6.

1. Use water for the liquid.
2. Use milk for the liquid.
3. Use cream for the liquid.
4. Use cream for the liquid and omit the butter.

C. Time of adding the fat.

1. Add fat at first so that it is in the sirup during the cooking process.
2. Add fat after removing from the fire. Put fat on top of hot fudge, but do not stir until cool enough to beat. Compare flavor and texture with the fudge under C1.

D. The proportion of cocoa used.

The thermometers should have the same boiling point and all conditions should be carefully standardized. Follow directions under A.

1. Substitute 1 tablespoon (7 grams) cocoa for the chocolate. Cook to 114°C (238.2°F).
2. Substitute 2 tablespoons (14 grams) cocoa for the chocolate. Cook to 113°C (236.4°F).
3. Substitute 3 tablespoons (21 grams) cocoa for the chocolate. Cook to 112°C (234.6°F).
4. Substitute 4 tablespoons (28 grams) cocoa for the chocolate. Cook to 111°C (231.8°F).
5. Substitute 5 tablespoons (35 grams) cocoa for the chocolate. Cook to 110°C (230°F).

If D1 is too hard repeat the series cooking D1 to 113°C and decreasing the temperature 0.5° for each tablespoon of cocoa added. Place portions of the fudges away to ripen. Compare texture and flavor. Which proportion of cocoa do you prefer?

Write a summary of the factors that influence the flavor and consistency of fudge.

E. Variations.

1. Prepare fudge by adding 1 tablespoon of corn sirup to the recipe.
2. Prepare fudge by adding 2 tablespoons of corn sirup to the recipe. Compare flavor, texture, glossiness, and keeping qualities with fudge made under A, B, C, and D.
3. Prepare fudge by adding fondant to the fudge.
4. Use different commercial prepared fudge mixes, and compare with your products.

Experiment 7.

To determine the effect of a weak alkali and heat upon crystalline dextrose when it is used in fondant.

Recipe:

Crystalline dextrose	1 cup
Water	⅓ cup

1. Use distilled water and cook until a medium firm ball is formed in cold water. Cool to 50°C (122°F) and beat.
2. Repeat 1, but substitute hard water for the distilled water.
3. Use 20%, or ⅕ cup, of dextrose, and 80%, or ⅘ cup, of sucrose. Use distilled water, and cook until a soft ball is formed in cold water. What is the temperature? Cool to 50°C and beat.
4. Repeat 3, but substitute hard water for the distilled water.
5. Repeat 3, but add 200 parts of magnesium carbonate per million parts of water to the recipe. (This is less than the proportions of carbonates found in much of the water used in different sections of the country.)
6. Repeat 3, but add 1/64 teaspoon of soda to the recipe.
7. Repeat 3, but add 1 tablespoon of vinegar or lemon juice to the recipe. Cream of tartar, ¼ teaspoon, may be used for the vinegar or lemon juice.

The main principles of sugar cookery are covered, and some are repeated, in the preceding experiments. Some frostings and some candies have added substances, like egg white, which retard crystallization. The principles for cooking are the same as those used in cooking and preparing the candies of the preceding experiments. However, to have frostings a consistency to spread and cut well, variations in temperature of cooking from that of candy may be necessary.

Suggestions for Additional Experiments

1. Prepare chocolate fudge icing and use on cake or cookies. Determine the temperature to which the sirup should be cooked.
2. Substitute brown sugar for white sugar in icing.
3. Make caramel or burnt-sugar icing by melting one-half the sugar to be used to a golden brown color. Then dissolve in water. Add the remainder of the sugar, and the butter, and cook to the same temperatures used for chocolate fudge icing. Which temperature produces the best texture of icing?
4. Prepare boiled icing by pouring the cooked sirup over beaten egg white. Prepare an outline for making this type of icing, giving variations in temperature to which the sirup is cooked before adding to the egg white and the temperature to which the sirup is cooled before adding the sirup to the egg white. Vary the amount of sugar used for different proportions of egg. Consult any reference that you wish for making your outline and use the results of any of the sugar experiments.

For a control use 1 cup sugar, 200 grams, ¼ cup corn sirup, 82 grams, and ¼ cup of water. Cook to 119° or 120°C (246.2–248°F), and pour slowly into 1 stiffly beaten egg white, beating as the sirup is added. For divinity beat until pieces dropped on wax paper will hold their shape.

CHAPTER
4

Frozen Foods

A pure liquid has a definite freezing point at which the fluid changes into a solid state. Water freezes at 0°C (32°F). A liquid may be supercooled before freezing; i.e., the temperature of water may drop to −4°C or lower. But the slightest movement or the addition of a crystal will cause the water to crystallize and the temperature to rise to 0°C, for water in freezing gives off heat. A gram of water in changing from 0° to ice at 0°C gives off 79.9 (or about 80) calories of heat.

Lowering of the Freezing Point

The addition of a solute to water or other liquid lowers the freezing point, the depression being proportional to the concentration of the solute. A gram-molecular weight (mole) of a non-ionized substance such as sugar in a liter of water lowers the freezing point 1.86°C. The lowering of the freezing point continues as long as the solvent will dissolve the solute. If no more than 3 moles are soluble the freezing point cannot be lowered more than 5.58°C.

Ionized substances and the freezing point. NaCl belongs to the groups of electrolytes which dissociate into ions in solution. For such solutes, the lowering of the freezing point is proportional to the initial concentration and the extent of ionization. If a mole of NaCl (58 grams) in a liter of water is completely ionized there will be 1 mole of Na ions and 1 mole of Cl ions. The lowering of the freezing point will be 2×1.86 or 3.72°C.

$CaCl_2$ lowers the freezing point to a greater extent than NaCl. It is more soluble than NaCl, and so a greater number of moles dissolves and also ionizes into three ions, 1 Ca and 2 Cl ions.

Since sugar does not ionize to an appreciable extent in solution, its lowering of the freezing point is in direct ratio to its molal concentration. Substances that are not very soluble, such as fat in milk, do not lower the freezing point appreciably because a very small fraction of a mole is dissolved. Substances with very high molecular weights like proteins also do not depress the freezing point to an appreciable extent, since such a small portion of a mole is soluble in a liter of water.

The freezing point of many foods like milk, meat, and fruits, is lower than that of water, owing to dissolved sugars, electrolytes, or both.

Freezing Mixtures

NaCl or $CaCl_2$ is often added to ice for a freezing mixture. The salt forms a solution on the surface of the ice, which is not in equilibrium with the ice. Thus more ice melts, heat is absorbed, and the temperature is lowered. The diluted solution so formed dissolves more salt, with consequent melting of ice, absorption of heat, etc., until the cryohydric point is reached. At this point the solution becomes solid and separates into ice and salt. If all the salt is dissolved the temperature is not lowered beyond the point when the solution contains the highest concentration of salt. If all the ice melts, the temperature cannot be lowered to a greater extent.

The lowest temperature obtainable with NaCl and ice is about −22°C, with $CaCl_2$ and ice about −55°C. At the cryohydric point 29 parts of NaCl are soluble in 71 parts of water. This proportion of salt to ice is about 1 to 3 and is often used in freezing mixtures.

Preservation of Food by Freezing

Preservation by freezing includes the control of deteriorative changes brought about by microorganisms, postharvest changes in fruits and vegetables, post-mortem changes in meat and poultry and postpreparation changes in precooked foods.

In general, the quality of a food is not improved by freezing or by frozen storage but is dependent upon the quality as it goes into the freezer. Thus it is important that the product be processed and frozen before deteriorative changes lower the quality. As suggested by Gortner et al. (3), more emphasis should be placed upon "quick to the freezer" and "quick cooling" than upon "quick freezing." Some factors such as packaging, rate of freezing, and time and temperature of storage are common to all frozen foods. Details for preparation of different foods can be obtained from the extension service or the state experiment station of each state. There are also several reference books on the principles of freezing, procedures, and commercial practices (1, 9).

Changes in frozen food. The changes that occur in the frozen food include (*a*) the growth of ice crystals, (*b*) changes of the colloids through aging, (*c*) oxidative changes brought about by residual oxygen in the food or through contact with oxygen of the air or oxygen within the container (the reaction may or may not be catalyzed by enzymes or metallic catalysts), (*d*) changes brought about by dehydration, (*e*) changes in pigments, and (*f*) changes from as yet undetermined causes.

Small ice crystals (7) are more soluble than larger ones. And, owing to surface energy tending to become a minimum, when both are found in a saturated solution the larger ones grow at the expense of the smaller ones. This natural growth of ice crystals is faster at higher temperatures and can be hastened by fluctuation of storage temperature. When thawed, large ice crystals leave relatively large vacuoles in tissues of meat and vegetables and fruit with a high water content.

Deteriorative changes in frozen foods have been ascribed to various causes such as autolysis, lipolysis, proteolysis, and oxidation. In general, enzyme action is slowed down in frozen foods. Mergentime and Wiegand (25) found that a proteolytic enzyme extracted from green peas was more active in products supercooled to −10°C than when the product contained ice crystals. Comments are made on other enzymes at appropriate places in the discussion of frozen foods. The concentration of salts may bring about denaturation of some of the soluble proteins. Fast freezing and low storage temperatures tend to minimize the extent of denaturation (34).

Water content of foods. The water content of foods varies greatly. It occurs as both free and bound water. Theoretically only the free water freezes. Complete freezing of all water in foods requires tremendously low temperatures. This temperature is not known for all foods. Lloyd and Moran (5) have reported that the bound water of gelatin is unfrozen at about −105°C. The bound water is held by proteins, starches, and possibly other substances. Since the water is not completely frozen it is important, particularly for foods packed in sirup, that the containers be leakproof and be stored upright in the locker. Otherwise unfrozen sirup gradually leaks over whatever is below it in the freezer.

Daughters and Glenn (2) found no bound water in rhubarb and spinach, very little in snap beans, around 5–6% in green peas, and about 34% in Golden Bantam corn. The bound water in bread (8) may be over 50% of the total water present. The total water content of foods like asparagus, cucumbers, and tomatoes is over 90%, that of fruits like peaches and pears is over 80%. The texture of foods like tomatoes, cucumbers, and celery is impaired by freezing. These foods do not freeze satisfactorily.

The volume of ice is about $\frac{1}{11}$ greater than that of the water from which it is obtained. Hence, when foods high in water content, but low amounts of bound water, are frozen the pressure becomes greater than in foods of low water content, and the cells are ruptured. On the other hand, food products like bread and cake which contain smaller amounts of water can be frozen without perceptible injury to the cell structure.

Packaging. Packages for frozen foods are varied. They may include (*a*) tin containers as used in concentrated fruit juices, (*b*) the waxed cartons, sometimes with overwrap, used for fruits and vegetables and precooked foods such as creamed dishes, (*c*) the various wraps used for meats, poultry, and precooked foods such as cake and bread, and (*d*) the Cry-o-Vac type used for poultry. Winter (10) discusses the efficiency and cost of the various wraps. The *Quick Frozen Foods* magazine has an annual packaging review.

Packaging protects the product from contamination with dirt and micro-organisms, and increases the ease of handling. For efficient preservation of the food product for more than a few days' storage, the package should be moisture- and vaporproof, and lessen or exclude the amount of air coming in contact with the food. Because of differences in vapor pressure in the food product and the storage space, ice from the food sublimes to water vapor. If the package does not prevent the escape of the water vapor, the vapor collects as frost on the freezing coils or walls of the storage space. The loss of this water vapor leaves desiccated areas on the surface of the food, which become more extensive and deeper as the dehydration proceeds. This dehydration causes discoloration, a spongy-like texture, and a dried-out tissue with off flavors. If the water vapor cannot escape through the package, it collects as frost in areas in which the package is not in contact with the food surface. It is because of this and to exclude as much air as possible that the packaging material should as far as possible fit the food product tightly. The oxygen of the air may bring about oxidative rancidity in fats, oxidation of ascorbic acid, and other constituents. The report of Ramsbottom et al. (53) on the effect of 40 years' storage on the quality of frozen beef rounds is an excellent example of the importance of good packaging and the exclusion of air. After 40 years' frozen storage in hermetically sealed tin cans, the rounds in tins that had not rusted or broken had a layer of dehydrated tissue about $\frac{1}{16}$ inch in depth. But, the deeper portions of the lean resembled fresh beef in color, in histological structure, in nutritive value, and in chemical composition. The fatty tissue of the round was rancid. In palatability of the lean there was a slight preference for the flavor of fresh beef.

In addition to impermeability of the package to water vapor and oxygen, other considerations in a package material are its ease of handling at room and low temperatures, its greaseproofness, physical toughness (desiccated areas develop at broken and torn spots), lack of odor and flavor, and economy of space. Appearance is important in commercial packages. The cost of the package should not be prohibitive, but it is too often the only criterion for purchase of the wrap. Poor locker papers are common on meats.

The rate of freezing. It is difficult to define fast and slow freezing precisely. The definition may be based (*a*) on the time required for the drop from one temperature to another, (*b*) the rate of progress of the ice zone through the food, and/or (*c*) upon whether intra- or intercellular freezing occurs. Moran (6) states meat is quick frozen if the time is 0.5 hour or less for the temperature to drop from 5°C to −5°C. Others have given similar definitions. Woodroof (11) says that plant tissue is quick frozen if the ice zone through the food forms at the rate of 0.3 cm per minute or faster and that the ice crystals should not exceed 10, 15, and 30 μ, respectively for thickness, width, and length. Both intra- and intercellular freezing may occur in the same sample. There is general agreement that faster freezing produces smaller ice crystals and that slower freezing produces larger crystals. Emphasis in early frozen food work was often upon the rate of freezing in relation to rupture of cells of the thawed food and not upon the relation of rate of freezing to the nutritive value and quality or palatability of the food when ready to serve. The quality of some foods may be better if quick frozen, others if slowly frozen, and for still others such as cake, bread, and starchy vegetables the rate of freezing may make no difference. Intermediate rates of freezing, such as are obtained in good lockers, home freezers, and commercial practices should produce good-quality frozen food, provided the quality was good when freezing was started.

The temperature and time of storage. Since the growth of microorganisms is stopped at temperatures around −9°C, Gortner et al. (3) state that this temperature is a logical upper limit for the storage of frozen foods. In addition, the deteriorative chemical and enzymatic changes are not inhibited sufficiently at the freezing point of the food product. Although retardation of the chemical and other changes is increased as the temperature is lowered, economic considerations rule out very low storage temperatures. Agreement is general that storage should be −18°C (0°F) or lower. The time that a food can be held in frozen storage and retain its quality is closely related to the storage temperature, although it varies with the food, its packaging, and prefreezing treatment. In general, the lower the storage temperature, the longer the food can be stored. Ramsbottom (52) has demonstrated that temperatures of −3°, −7°, −12°, −18°, −23°, and −29°C (26°, 20°, 10°, 0°, −10°, and −20°F) are progressively more effective in retaining the quality of fresh meat. Hall et al. (42) emphasize a low storage temperature for pork. They used storage temperatures of −12°, −18°, and −23°C. At the lowest storage temperature the palatability scores were higher and the peroxide value and acid number of the fat were lower.

One example will be cited of the effect of storage temperature upon the quality of vegetables. Peas were processed at the Iowa station and divided into 4 lots. The test panel's rating showed that after storage for 9–10 months at −7°, −12°, −18°, and −23°C the deteriorative changes were progressively greater as the storage temperature was elevated. Among the changes were loss of chlorophyll with development of a yellow color, decrease in tenderness, loss of sweetness, and a decrease in other palatability factors.

Fluctuating storage temperatures. Frozen foods may undergo several fluctuations of temperature before they reach the consumer. From studies on ground beef, ground pork, snap beans, and strawberries held at a "constant" temperature of −18°C and at a fluctuating temperature of −18° to −23°C, Hustrulid et al. (4) concluded that the fluctuating temperature did not affect the palatability and nutritive value of the products, provided the packaging was adequate. Snap beans and strawberries ıad as high an ascorbic acid content in the fluctuating temperature freezer as in the constant temperature one.

Ice Cream

The composition of ice cream must meet the state legal requirements. These vary considerably in the different states. Some states specify only the minimum requirement for butter fat, whereas some include other requirements, such as solids-not-fat, total milk solids, food solids per gallon, stabilizer, and amount of air per gallon (15).

The following proportions of ingredients are recommended for an excellent commercial mix and an average composition, respectively.

	Sommer (14) %	Turnbow et al. (15) %
Fat	12.5	10–12
Serum solids	10.0	10.5–12
Sugar	16.0	12–15
Stabilizer	0.25–0.50	0.2–0.4
Egg yolk solids	0.50	0.30

Stabilization of ice cream. Ice cream is a more complex system than milk or cream. It not only is an emulsion but also is a foam and in addition has a system of ice crystals.

Fat globules. Butterfat globules add richness and flavor to the ice cream, but if they clump the ice cream is less smooth. If the cream churns during freezing, the texture is soggy. Ice cream contains more fat than milk does. The ice-cream mix is homogenized to divide the fat globules. This gives a smoother texture, increases the whipping properties of the mix, and may also affect the protein (14). According to Little (12), the fat globules in milk vary from 1 to 18 and average 7.5 μ. When the ice-cream mix is homogenized, the size of the fat globules may be reduced to 0.5 μ. The surface area of fat is increased to 16 to 50 times that of the same weight of fat in milk. As a consequence, there are not enough phospholipids and proteins to cover the surface of the fat to stabilize it. Hence, more milk-solids-not-fat, or serum solids, are added to the ice-cream mix. If too much of these milk-solids-not-fat are added the ice cream may become sandy on long storage because they contain considerable lactose sugar, which is rather insoluble at low temperatures and crystallizes; too little does not stabilize the fat.

The increased surface area of the fat permits faster action of the lipase enzyme with consequent detrimental effect to the fat flavor. Hence, the ice-cream mix is pasteurized to destroy the lipase enzyme as well as pathogenic organisms.

Air cells. During freezing air is incorporated into the ice-cream mix. When the amount of air incorporated is too low (14) the ice cream is soggy; with too much air the ice cream is frothy. As discussed in Chapter I, a foam, to remain stable, must have a surface film that does not coalesce readily. In ice cream this film consists mostly of proteins, but other factors such as the rigidity of the frozen mix also affect the result. The incorporation of air is known as overrun. It is the increase in volume of the ice cream over that of the mix.

Ice crystals. The factors affecting the size of crystals have been discussed in the chapter on Sugars. They also apply to ice crystals. Since the ice-cream mix is agitated during freezing the initial ice crystals are small. The fat, proteins, and stabilizer tend to keep them from growing. During storage the ice cream is often subjected to fluctuations in temperature. Since small crystals are more soluble than larger ones (7), they melt first, and, when the temperature drops, owing to surface energy tending to become a minimum, they recrystallize on the larger crystals. The function of the stabilizer is to prevent this crystal growth so that the ice cream texture does not become coarse.

Lists of stabilizers that may be used in ice cream may be found in many sources (13, 14, 15). Little (12) gives a good discussion of the use of emulsifiers and stabilizers; Potter and Williams (13) compare the efficiency of some of these substances. The stabilizers include gelatin and many gums and substances of plant origin: agar-agar, carob-bean gum, cellulose gum, gum arabic, gum karaya, gum tragacanth, Irish moss, oat gum, and sodium alginate. This list is very similar to that of emulsifiers permitted by the Food and Drug Administration in French dressings.

Ice cream made in refrigerator. The temperature control should be set low to obtain faster freezing and thus smaller ice crystals in ice cream made in a refrigerator. Other means of preventing the development and growth of large crystals are: (*a*) some agitation during freezing, (*b*) the occulsion of air, and (*c*) addition of substances to prevent crystal growth. The mixture can be stirred occasionally in the freezing tray, but better results are obtained by removing the mix after freezing has started to a chilled bowl and beating rapidly with a rotary egg beater to occlude air. The procedure can be repeated. Other ways of obtaining small air bubbles in the mix are to use (*a*) whipped cream, (*b*) whipped evaporated milk, or (*c*) beaten egg white in the mix. Egg white, gelatin, marshmallows, chocolate, cornstarch pastes, and commercial ice-cream mixes may all be used to aid in preventing crystal growth.

Fruits and Vegetables

The physiological aspects of freezing fruits and vegetables have been reviewed by Joslyn and Diehl (20).

The kind and variety. Joslyn and Diehl (20) cite the following statement by Heiss: "Conditions for growth and choice of variety have a greater influence on the quality of frozen fruits and vegetables than technical factors." Quality products have not been obtained by freezing celery, cucumbers, lettuce, onions, radishes, and tomatoes. Among the vegetables that can be successfully frozen are peas, corn, snap beans, lima beans, broccoli, asparagus, squash, spinach, artichokes, beets, Brussels sprouts, cauliflower, carrots, greens of various types (kale, mustard, chard, etc.), sweet potatoes, and rhubarb.

Black raspberries processed at the Iowa Experiment Station have been seedy, the freezing intensifying this property. Senator Dunlap and Beaver strawberries are among the best for growing in Iowa; some varieties of plums become bitter, some develop tough skins, others are desirable. Some varieties of snap beans become tough, some varieties of sweet corn always have tough skins, other varieties are satisfactory in this respect.

Maturity. The maturity of the fruit and vegetable when harvested for freezing is as important as the variety. Underripe fruits lack the full flavor of the ripe ones. Starchy vegetables such as sweet corn, peas, and lima beans that are too mature are hard and do not yield high-quality products. Other vegetables like snap beans become woody if too mature.

Prefreezing treatment. Scalding of vegetables before freezing is necessary to inactivate enzymes so that discoloration, changes in texture, and the development of off flavors are prevented. The time required for scalding to inactivate the enzyme systems varies with different vegetables. For example, peas, depending on their size, require 30–60 seconds; small ears of corn on the cob take 4–7 minutes. The rate of heat penetration into the vegetable varies with its size, shape, the initial temperature of the vegetable, its amount in relation to the quantity of boiling water or steam, its thermal conductivity, and the initial temperature and rate of heating of the scalding medium. A longer time is required for scalding in steam than in boiling water. Rapid cooling of the vegetable is essential.

Time for deterioration. Although scalding has been accepted as necessary to preserve the quality of vegetables held in frozen storage for several weeks, questions are often asked about short storage periods. Noble and Winter (26) have shown that scalding improves the quality of the vegetables stored for short periods. They compared scalded asparagus, green beans, and sweet corn with corresponding unscalded samples at the end of a 24-hour freezing period at −23°C and after storage at −18°C for 1, 2, 3, and 4 weeks. The criteria for comparison were palatability scores, the amount of ascorbic acid present, and color measurement by the Munsell method. The unscalded vegetables showed marked deterioration by all criteria. Off flavors were noted in the unscalded products as follows: asparagus and unshucked corn in 4 weeks, snap beans in 3 weeks, and husked corn in 1 week. Scalded vegetables showed no perceptible change.

Unscalded cabbage loses its green color, starts turning brown, and develops an off flavor in less than 4 weeks when stored at −18°C. Although cabbage is not usually frozen, it can be obtained throughout the year, and can be used for class work when short storage periods are desirable.

Enzymes causing deterioration. Joslyn (19) in his review of enzyme activity in frozen vegetable tissue states that the changes in raw or insufficiently scalded vegetables are caused by enzymes not inhibited by low temperature and ice formation. The particular enzymes are unknown, but it is believed that one or more of the respiratory enzymes are involved in producing the deteriorative changes. The malodorous substances (19) are volatile with steam, can be collected in the distillate, and are extractable with solvents like ethyl ether, petroleum ether, or benzene. Acetaldehyde (19, 20), although not the cause of the off flavor, is one of the byproducts of the reaction in producing the off flavor. Gutterman et al. (16) used peas and asparagus as test materials. They found that when the acetaldehyde level exceeded a certain point the test panel considered the product inferior in quality or inedible.

Lee et al. (24) harvested Thomas Laxton peas and divided them into 3 parts. A scalded and an unscalded portion were frozen and stored at −18°C for 5 years. The third part was used for analysis of total solids, total nitrogen, reducing sugars, sucrose, and starch. No significant changes were observed in these constituents after storage for 5 years. Since no changes occurred in total nitrogen, the possibility that the off flavors produced in the peas were volatile amines or nitrogen compounds was ruled out. The peas from which lipid matter was extracted were dried from the frozen state under vacuum. The residue remaining after ether extraction of the unscalded peas did not have an off flavor, but tasted like a cereal with a slight pea flavor. The extracted lipid material had a decided odor of rancid fat. The peroxide number of the lipid material from the unscalded peas had increased, the iodine number was reduced, and the acid number increased during frozen storage. The data from the lipid tests are summarized in the accompanying table.

YEAR HARVESTED	STORAGE YEARS	TREATMENT	PEROXIDE NUMBER	IODINE NUMBER (Hanus)	ACID NUMBER
1950	0	Unscalded	0.0	98.0	22.6
1950	0	Scalded	0.0	99.2	23.0
1945	5	Unscalded	27.3	88.7	97.2
1945	5	Scalded	0.0	98.0	18.6

From their results the authors concluded that rancidity of the lipid fraction was one of the primary, if not the principal cause of off flavor in unscalded peas. They also found that the carotene and chlorophyll were reduced in the unscalded peas.

Reeve (29) found that some of the off odors developed in dehydrated carrots during storage are related to oxidation of oils and carotene. During scalding the lipoprotein of the carrot tissue is broken down.

Type of pack for vegetables. Vegetables, after cooling, may be dry or brine packed. The salt content of the brine may be 1–2%. Joslyn and Diehl (20) make the following observation: Diehl and his associates in the U. S. Frozen Pack Laboratory repeatedly observed better retention of texture (turgor), color, and other desirable characteristics in the wet- than in the dry-packed vegetables. Plagge (28) reports a brine pack is especially desirable for peas, snap beans, asparagus, and carrots. Because spinach does not drain readily, it is practically a wet pack without the addition of brine. The brine affords protection from the oxygen in the air surrounding the dry pack. The vegetable is cooked in the weak brine. For obvious reasons vegetables are dry packed commercially.

Rate of freezing fruits and vegetables. Lee and coworkers (21, 23) froze vegetables very slowly by putting the cartons in insulated boxes in still air at −18°C, very rapidly by immersing the cartons in liquid air, and at intermediate rates. They found that the various rates of freezing did not produce significant differences in palatability or vitamin content of peas, snap beans, corn, lima beans, and spinach. Very rapid freezing produced a better texture in asparagus. Lee et al. (22) also found that strawberries, raspberries, and sliced peaches packed in sirup showed few differences in vitamin content, appearance, and flavor, regardless of the rate of freezing. Woodroof (32) states that rapid freezing, from the standpoint of cell structure, is not important in peas, corn, and lima beans.

Although fast freezing was emphasized in early work with frozen foods, observations like the following began to appear in the literature. Weigand (31) as early as 1931, after comparing strawberries frozen at various temperatures, made the following comment: "It seemed, however, from the results obtained, that the pretreatment given the fruit was the most important factor to be considered. After the proper pretreatment any good freezing method will prove satisfactory and will give a uniformly well colored and flavored product."

Thawing and cooking. Most frozen fruits are more palatable if served just thawed or slightly frosted. During thawing juice is lost from the fruit, some fruits collapse, and the texture of some tissues becomes slick. To have no left-over thawed fruits, it is satisfactory when only 1 or 2 servings are needed from a small commercial package to cut or saw off the servings desired, while the contents are frozen. The cut surface of the left over part is carefully covered and returned to the freezing compartment.

The points to be considered in the thawing procedure for vegetables are: (*a*) how to obtain uniform cooking, (*b*) palatability, and (*c*) retention of nutritive value. Corn on the cob should be defrosted. Otherwise, when the kernels are ready to serve the cob is still frozen, or, if the cob is defrosted, the kernels are overcooked. Stalks of asparagus, blocks of frozen greens, cooked squash, and cooked sweet potatoes cook more uniformly if defrosted. Other vegetables may be thawed before or during cooking.

In serving frozen vegetables it is preferable to use very little water for cooking, serve as soon as done, and not overcook. The cooking time for frozen vegetables is approximately half as long as for fresh ones. Frozen vegetables like fresh ones lose more nutritive value (the soluble vitamins, salts, sugars, proteins) if a large excess of water remains after cooking. The thawing procedure may also cause unnecessary loss of ascorbic acid. Jenkins et al. (18) found there was no appreciable loss of ascorbic acid when peas were allowed to thaw in their original sealed carton at room temperature for 24 hours. On the other hand, Todhunter and Sparling (30) found that peas, when removed from the hermetically sealed container, and then allowed to stand at room temperature lost 16% of their ascorbic acid in 30 minutes and 27% in 1 hour; if stored in the refrigerator at 4°C 25% was lost in 24 hours.

Precooked frozen fruits and vegetables. A few precooked vegetables such as pureed pumpkin, squash, and sweet potatoes, which are packed in a solid pack, keep well in frozen storage. Woodroof and Atkinson (33) found that scalded lima beans, snap beans, soybeans, okra, field peas, and cream-style corn kept well for 1 year when the loose pack was stored at −18°C. Cooked vegetables from identical lots were only fair to poor in quality. Paul et al. (27) also found that precooked frozen asparagus, carrots, green beans, broccoli, and cauliflower when reheated for serving were flavorless or off flavor, soggy, mushy, and fair to poor in color compared with scalded vegetables. The ascorbic acid content was also less in the precooked than in the scalded vegetables.

Most fruits are frozen because the raw product is preferred to the cooked one. Hohl (17) found cooked, pureed, frozen apricots, peaches, and pears kept their flavor and color for a year. Woodroof and Atkinson (33) report that apples, blueberries, raspberries, blackberries, and plums, which have been scalded, are superior in flavor to those which have not been heated, but only if the preheated fruits are "solid-packed" without bubbles or air spaces, in rigid, leakproof, moistureproof containers.

Frozen Meat and Poultry

Robertson (55) discusses the advantages of prepackaged frozen meat for the consumer and the maintenance of its quality. Among the advantages are the discarding of waste materials.

Prefreezing treatment. Beef, lamb, and veal are aged for varying periods, 7–10 days, or longer, to increase the tenderness before freezing. Pork is aged 2–3 days. It has been reported that freezing increases the tenderness of meat. See p. 227.

Poultry after slaughter is often cooled rapidly in slush ice. Holding roasters and older birds overnight appears to bring about sufficient tenderness by aging. Broilers tenderize very rapidly within 2 to 3 hours after slaughter (48), so that it is not surprising that no differences in tenderness of broilers was found after aging 2 and 18 hours before freezing (57). Muscles of roasters, however, aged 2 hours before freezing were less tender than those aged overnight (47).

Poultry is eviscerated before it reaches the consumer. It may be cut into pieces for cooking. Meat cuts are trimmed and may be boned. Hamburger and sausage are ground.

Freezing. Although the rate of freezing affects the location and size of the ice crystals and the color of red muscles, it has not been shown that it materially affects the quality. Stewart et al. (57) did not produce detectable differences in the palatability owing to freezing at temperatures of −20.5°, −46°, and −68°C.

Callow (34) states that microscopically there is a zone of very small ice crystals at the surface which merges into a zone of larger and larger ice crystals. Ramsbottom et al. (54) found that when beef rounds were frozen in air blast at −32°C the ice crystals ranged in size from small ones within the fibers in superficial lean to large crystals between the fibers at a depth of 4 inches. The meat in these tests between ¼ and ½ inch from the surface could be classified as quick or slow frozen, depending on the criterion used to define quick freezing. When the definition of quick freezing was 30 minutes or less to lower the temperature of the meat from −0.5° to −4°C, the meat at ¼ inch and at ½ inch from the surface was quick frozen. When the presence of intrafiber ice crystals was used as the measure of quick freezing, only the meat to a depth of ¼ inch could be considered quick frozen.

Hiner et al. (43) found that interfibrillar ice areas occurred when beef muscle from the short loin was frozen at −8°C. The size of the ice crystals and ice areas between fibers decreased as the freezing temperature was lowered (−8°, −18°, −23°, −40°, and −81°C). At the lowest temperature the ice formed within the fibers, so that the fibers were split longitudinally into several sections.

Aging and intrafiber freezing. The extent of aging the meat before freezing has some effect upon intrafiber freezing. Ramsbottom and Koonz (51) found that, if beef steaks were frozen at an ambient temperature of −35°C within a few hours after freezing, the ice crystals were small and located within the fibers; when similar beef was aged a month before cutting and freezing the steaks, the ice crystals were very large and located interfibrillary. Stewart et al. (57) froze broilers (after aging 2 or 18 hours) at −68°, −46°, and −20°C. Vacuoles within the fibers after cooking the broilers were considered to be spaces formerly occupied by ice crystals. These vacuoles were found in the breast muscles of broilers aged 2 hours and frozen at −68° or −46°C. In the thigh muscles, the vacuoles were found only from broilers aged 2 hours and frozen at −68°C. Practically no vacuoles were found in fibers of muscles from broilers aged 18 hours before freezing regardless of the freezing temperature. These results suggest that the water is more easily transferred from the fibers to the spaces between the fibers after aging occurred or what Callow (34) calls an open structure has developed.

Pressure. Because some pieces of meat that are frozen are large the pressure in the interior from expansion of ice may be great. Callow (34) cites instances in which 200 pounds per square inch have been measured. When the pressure becomes great enough the ice on the surface is cracked.

Color. Ramsbottom et al. (54) found that the rate of freezing affected the color of beef. Steaks frozen slowly at −7°C (20°F) were much darker than the corresponding fresh steaks. Those frozen at −80°C (−110°F) were much lighter, whereas those frozen at −29°C were similar in color to the fresh steaks. This difference in color is attributed to difference in size of the ice crystals. The meat frozen rapidly and with the smallest ice crystals appeared lighter.

Fat content of meat. Ramsbottom et al. (54) found the rate of freezing was affected by the fat content of the meat, the freezing rate being accelerated with increase in fat content. This is accounted for by the greater amount of moisture with consequent higher heat capacity of the lean meat. Beef, pork, lamb, and veal froze at similar rates when the fat contents were similar.

Deteriorative changes in storage. Discoloration of surface areas of cut muscle may be brought about by myoglobin being changed to metmyoglobin. Dehydration (desiccation or the so-called freezer burn) may occur on the skin of poultry and on the surface of meat. The skin is bleached and dry looking; the surface of the cut muscle becomes lighter in color and spongy. Hydrolysis of the fat by the lipase enzyme does not appear to occur to a great extent in beef. Ramsbottom et al. (53) found the free fatty acid content of beef hams (the anterior lower part of the round) after 40 years' storage to be about the same as that of fresh beef hams. The data for free fatty acid and peroxide values is summarized in the accompanying table.

STORAGE	LOCATION OF FATTY TISSUE	FREE FATTY ACIDS (as oleic) %	PEROXIDE VALUE me/kg
40 years.........	Superficial	0.99	19.71
40 years.........	Deep	0.36	12.90
Fresh.........	Superficial	1.20	1.22
Fresh.........	Deep	0.35	0.75

Ramsbottom (52) also found a low free fatty acid content in beef stored for 7 years.

Pennington (50) noted that the acidity of fresh chicken fat varied considerably from bird to bird. This has been substantiated by all subsequent investigators. Cook and White (35) found that the free fatty acid content of poultry fat after storage varies among birds, is usually low, and is not related to the storage conditions at freezing temperatures.

Hall et al. (42) found that the free fatty acid content of pork roasts increased with time of storage, which was 12, 24, 40, 56, and 72 weeks, particularly for the roasts stored at −12°C (10°F). There was only a slight increase (none in some samples) of free fatty acids in roasts stored at −23°C.

Proteolysis in frozen beef does not seem to be extensive, if the criterion is the amount of amino nitrogen (53). The amount of amino nitrogen in beef stored 40 years was 0.07%, in fresh beef 0.08%.

Although freezing rates do not produce detectable differences in the palatability of broilers, serious changes in flavor and juiciness may occur in poultry, owing to time and temperature of storage. The giblets deteriorate most rapidly, the breast muscles least, whereas the thigh muscles are intermediate (64, 65). A storage temperature of −8°C was unsatisfactory, even for 3 months. As the storage temperature was lowered the deteriorative changes in flavor decreased.

Rancidity. Probably the most devastating deteriorative change in meat and poultry is development of rancidity in the fat. Since fat of different animals varies in its unsaturated fatty acid content, the fat of different animals also varies in susceptibility to oxidative rancidity. Pork fat becomes rancid more readily than that of beef, lamb, or veal. Turkey fat is more susceptible to rancidity than chicken fat. There is great variation from animal to animal within a species in respect to fat stability.

Development of rancidity is affected by (*a*) the feed the animal has received, (*b*) the exposure of cuts to oxygen, (*c*) the prefreezing treatment, (*d*) the time and temperature of storage, (*e*) the addition of substances such as salt, sage, pepper, and antioxidants, and (*f*) cooking.

The feed of different lots of chicken was varied by Schrieber et al. (56). Although the fat extracted from the lot of birds fed alfalfa was the most stable, the carcass fat of these birds was the most susceptible to rancidity. Fish oil fed to chicken for 1–2 weeks before slaughter also decreased the stability of the carcass fat.

Prefreezing treatment may include many practices. Some of these are: a premortal fast, a preliminary holding time before putting in storage, evisceration of poultry, and precooking. Wagoner et al. (59) found that starving the poultry for 16 hours before slaughter increased the storage stability of the carcass fat. Cook and White (36) found that the longer the interval was between cooling and freezing the higher the peroxide value of the fat and the greater the deterioration in subsequent frozen storage. Wagoner et al. (60) found similar results. It is because of deterioration of the fat that pork is not held long before freezing although the aging process might be advantageous in increasing the tenderness.

The internal fatty tissues of poultry are less stable than those of the skin (35, 38, 56). Evisceration exposes these internal fatty tissues to oxygen. However, the advantages of evisceration overbalance the disadvantage of the lessened stability. In practice, good packaging and a low storage temperature tend to protect against development of rancidity. Then too, the neck skin is pressed close to the crop cavity, and the giblets and neck may be placed in the body cavity. This lessens the exposure of internal body fat to oxygen. Wagoner et al. (61) also found that the reduction in exposed surface by disjointing the poultry as for frying and wrapping in a compact package improves the stability of the chicken fat during storage.

Storage time and temperature. Pork roasts (42) were stored at three temperatures, −12°, −18°, and −23°C (10°, 0°, and −10°F) for varying periods of time from 12 to 72 weeks. No changes occurred in the outside fat of roasts stored at −23°C, whereas the peroxide formation was extensive at −12°C particularly after 56 and 72 weeks of storage. The peroxide values of beef fat stored 40 years have been given. The peroxides for fat of steaks stored 7 years were low, the averages for the 3 groups varying from 0.92 to 1.13 (52). The peroxide development in pork chops was a function of both time and temperature of storage. Rancidity was not uniform throughout the cuts but developed first on the surface of the cut.

Salt, seasoning, and cooking. Lea (45) observed that NaCl accelerated the oxidation of raw pork fat. DuBois and Tressler (39) reported that salt added to ground pork or ground beef activated the oxidation of the fat, whereas pepper, sage, mace, and ginger have an antioxidant effect. Watts et al. (62, 63) also found that in addition to NaCl a *p*H range of 6.5 to 4.8 also accelerated the oxidation of raw ground pork fat. Precooking the pork before freezing prevented the action of the acid and NaCl in accelerating the oxidation.

Lineweaver et al. (46) found that sufficient rancidity may develop during the cooking of turkey so that it is readily detected in creamed dishes. Adding an antioxidant, preferably during the cooking of the turkey, markedly retarded the development of rancidity.

Hall et al. (42) determined the peroxide values of the outside fat for 9 cooked fresh pork roasts and of the interior fat for 3 roasts. The peroxide number (me/kg) for the outside fat varied from 0.6 to 11.5, being above 8 for 5 of the roasts; that for the inside fat varied from 6.5 to 7.2. These investigators state it is evident that the amount of peroxide found in fat that has been roasted is not a reliable index of rancidity, for often no peroxide was found in the uncooked fat.

Defrosting frozen meat. *Time for defrosting.* In a study (49) in which several hundred cuts of beef, veal, lamb, and pork were defrosted during cooking, in the refrigerator (4–5°C), in the room (approximately 25°C), and in water (2 times the weight of the cut in water at 49°C was poured over the cut and left at room temperature), it was found that the chief determinants of defrosting time are the size of the cut and the defrosting temperature. Insulation, in the form of heavy packaging, could influence the defrosting time, but the one layer of cellophane used in the study had a small effect upon the defrosting time. As the defrosting temperature was elevated the defrosting time was shortened. Because water conducts heat more rapidly than air, it was found in comparative studies of cuts from the right and left side of the same animal (one submerged in water and left at room temperature, the other left at room temperature) that the cut in water defrosted more quickly. In general, when the cut was taken from −18°C storage, the time for the cut to reach the temperature at which ice starts to melt (about −2°C or 28°F) was twice as long in water than during roasting at 120°C and 3 times longer than for braised and boiled cuts; about 2 times longer was required in the room than in water for practically all cuts; and, 2 to 3 times longer in the refrigerator than in the room.

Defrosting weight loss, drip. The red fluid that oozes from the thawing cut constitutes the chief weight loss during defrosting, unless the cut is uncovered. Cuts defrosted in water may gain weight. The drip is usually sticky and always messy. On any unfrozen cut, if covered to prevent evaporation, drip may accumulate from cut muscles during storage. But, the amount of drip from a thawed cut may be much larger than from a similar fresh cut. Several factors affect the amount of drip obtained. Much depends on how and when the drip is measured, for the drip loss does not stop when the cut is thawed but continues throughout the holding period before cooking.

Empey (41) found that the *p*H of the muscle was the chief determinant of the amount of drip, although the osmotic pressure and the nature of the muscles also influence the result. The lower the *p*H the greater the volume of drip exuding from the muscle and the greater the weight loss.

Hiner et al. (43) found that the drip obtained from the longissimus dorsi muscle of the short loin of beef decreased as the freezing temperature was lowered from −8° to −81°C. Increased intrafibrillar freezing and rupturing fibers which permitted the proteins to reabsorb a large proportion of the frozen water is suggested as the cause.

Empey (41) found the rate of freezing did not affect the amount of drip obtained. He did find that increasing the storage period increased the amount of drip. Empey also found no difference in the amount of drip due to variation in age, sex, or breed of the animal and no difference between beef and mutton.

Callow (34) found that muscles frozen before rigor has developed have as high a drip loss upon thawing as those frozen after the development of rigor. Upon thawing the muscle passes into "thaw rigor." The shortening of the muscle fibers during the development of this thaw rigor increases the pressure within the muscle.

Ground meat. Meat that has been ground, frozen, and then thawed has little or no drip loss.

Cooking time and fuel. If the same cooking temperature (49) was used a cut that was frozen when cooking was started always required a longer time and more fuel than its thawed paired mate. The increase in time for cooking frozen cuts over that of similar thawed cuts cooked under the same conditions varied widely. In general, a little more than a third increase in time was required for the frozen than the thawed cut.

Cooking temperature. The preferable cooking temperatures for cuts that were frozen when cooking was started were the same as for thawed roasts. However, in general (49), the cooking temperature caused greater divergence in the cooking time, the amount of fuel required, and the cooking weight losses than it did in palatability.

Palatability. Under the conditions of the tests (49) the differences in palatability that could be attributed to the methods of defrosting, *i.e.,* during cooking, in the refrigerator, in the room, or in water, were negligible. Similar results were obtained in defrosting poultry by these four methods (44). Palatability scores were affected by the carcass grade, variation from animal to animal, variation from muscle to muscle, boning of the cut, length of frozen storage before cooking, the stage of doneness to which the roast was cooked, the cooking temperature, and the time of cooking. Tenderness was the palatability factor most often affected by animal and muscle variation, although some of these variations also affected the texture, flavor, and juiciness scores.

Robertson (55) thinks the quality of frozen meat is better if the cut is defrosted during cooking. He states the method of cooking is more important than the method of freezing.

Precooked frozen meat. Freezing cooked meats is a convenience as the remains of roast meat or poultry can be frozen, then thawed, and used as cold sliced cuts or made into prepared dishes. Precooked prepared meat dishes such as Swiss steaks, stews, and various types of creamed products may also be frozen.

The data reported in *Bulletin 385* (49) for palatability of frozen precooked roasts were obtained as follows: the roasts of beef, veal, lamb, and pork were scored just after cooking. The remainder of these roasts was frozen and held in frozen storage for average periods of 54–243 days. After thawing the roasts were again scored for palatability. For this second scoring the roasts were scored as cold cuts. Reheating would have increased the dryness by moisture loss. A study of the palatability data obtained in scoring these roasts and the results of a study by Tinklin et al. (58) indicate that in freezing the cooked roasts the following results were obtained: The texture and tenderness scores remained about the same as at the first scoring; but, the aroma, flavor of fat, and flavor of lean scores were lowered by freezing the cooked meat, but not always consistently. The juiciness scores were lowered, indicating that the freezing increased the dryness of the meat.

Part of the deterioration in flavor scores reported in *Bulletin 385* could undoubtedly be attributed to the length of storage. Hence it is interesting to study the palatability scores in Table 12. Turkeys were cooked at the oven temperatures indicated in the table. The large muscle from one side of the breast was used for scores and objective tests just after cooking.

TABLE 12

COOKED AND PRECOOKED FROZEN TURKEY

The palatability data were obtained by scoring the breast muscle from one side of the turkey just after cooking (first scoring) and from the other side after freezing the cooked muscle and storage for 1 week (second scoring). A total of 48 turkeys were used. Highest possible score, 10, Edgar (40).

Oven temperature, degrees C	Method of cooking	Scoring	Palatability Scores		
			Flavor	Tenderness	Juiciness
150	Without foil	1st	7.9	8.6	8.2
		2nd	7.7	8.1	7.8
150	In foil	1st	7.7	7.9	5.9
		2nd	7.0	8.2	5.6
205	Without foil	1st	7.9	7.9	7.0
		2nd	7.4	8.0	6.7
205	In foil	1st	7.5	8.3	5.4
		2nd	6.8	8.0	4.9

The large muscle from the other side of the breast was wrapped in foil, frozen, and stored at −18°C for 1 week, then thawed and rescored.

The statistical analyses indicated the lowering of the flavor and juiciness scores were significant at the 1% level, whereas those for tenderness were insignificant.

Frozen Rolls and Bread

The effect of freezing and frozen storage on baked bread, bread products, and bread dough has been reported by many investigators (66, 67, 68, 69, 70, 72, 73). Freezing the baked bread and bread products presents no difficulty, if properly packaged, for bread has been frozen in the far north and experimentally (71) for a long time. The most disputed question is whether bread dough can be successfully frozen, and if so, how and for how long?

Commercial frozen bread. According to Cathcart and Luber (67) commercially baked bread frozen at −23°C (−10°F) and held in frozen storage remained good for 20 days and salable for approximately 40 days. At −35°C it remained in salable condition for longer periods of time. The development of off aroma was the limiting factor for the time the bread could be stored. With the exception of a few specialty items, it is not practical to freeze bread commercially. The freezing, the frozen storage, and the packaging needed for freezing, increase the cost of the frozen item, without improving the product.

Viability of yeast in frozen doughs. The success of freezing bread and roll doughs is usually limited by how long the biological activity of the yeast cells may be maintained. Godkin and Cathcart (70) found that normal yeast activity may be retained 1–3 weeks in roll dough frozen and stored at −18° to −23°C. Charles and van Duyne (68), using dried active yeast and fermented, shaped dough, also found a significant decrease in gas production after frozen storage for 3 weeks. The plate counts of viable yeast decreased after the dough had been frozen for 3 weeks, but this decrease did not become significant until after 9 weeks of storage. The rate at which the yeast cells lose their activity (70) depends on: (*a*) the condition of the yeast before freezing, (*b*) the size or volume of dough, and (*c*) the rate of freezing.

The unfermented doughs hold up better than the fermented ones under frozen storage. Old yeast cells are less resistant to freezing than young ones. Different commercial brands and strains of yeast vary in ability to withstand freezing and frozen storage. Zaehringer et al. (73) found that freezing the dough causes a significant decrease in the volume of the bread made from compressed yeast, but not in that made from the dry yeast. A slow rate of freezing (70) is more detrimental to retaining viable yeast than a fast one.

The size of the dough affects the rate of freezing. A dough spread in a half-inch layer freezes more rapidly than a ball of dough.

The freezing rate is affected by (*a*) the freezing temperature, (*b*) the method of freezing (air blast or still air), (*c*) the size of the dough, and (*d*) the amount of insulation (package wrapping). The rate of freezing is probably slower for fermented doughs than the unfermented ones because of the large amount of occluded gas in the fermented dough.

Volume and palatability of rolls from frozen dough. Agreement is unanimous that bread and rolls baked from frozen dough are coarser and have a smaller volume than those from freshly baked dough. The tendency (73) for bread to have heavy layers was pronounced in dough stored 1 week or longer. After 9 weeks of frozen storage (68) the volume of frozen dough rolls was 65% of the mean original volume; of the brown-and-serve rolls, 94%; and of the frozen baked rolls, 91%. The aroma, texture, flavor, and even tenderness of the rolls baked from frozen dough decreases during storage. After 15 weeks of storage in one study (68) the rolls were considered unacceptable.

Other factors. The following have been suggested to obtain better products from frozen dough: (*a*) use the best proportion of ingredients (72), (*b*) eliminate the fermentation of the dough before freezing (72), (*c*) decrease the yeast by 50% and increase the sugar by 50% (72), and (*d*) thaw the dough in the original package because it prevents dehydration of the crust, and thus streaks in the bread. In two studies (72, 73) it was found that the dough kept better with smaller than with larger amounts of fat.

Fenton (69) says, "No frozen prepared food produces more conflicting reports than frozen, unbaked rolls. Some rolls are good, many failures; they never rise, but simply flatten out and develop a tough, leathery crust."

Frozen unfermented dough takes more time than if preparation of the rolls is started from scratch and the quality of the product baked from it is never as good as that baked from the same dough without freezing. Dough frozen in a ball takes a long time to thaw. If pressed into a thin layer, it thaws more readily, but still has to come to room temperature, ferment, and be shaped. Baking of fermented, shaped dough can be started while the product is frozen. Browning of brown-and-serve rolls as well as warming baked ones can also be started while the product is frozen.

The results from eight studies on frozen rolls in the author's laboratory are, in general, in agreement with reported results. The most striking result was the poorer quality of rolls baked from frozen dough, even when stored for only 2 days. It suggests that freezing may affect other constituents in addition to the yeast. It is known that some proteins are partially denatured by freezing. It is also known that starch gels (sauces, gravies) upon freezing become curdled. They can be recombined by reheating and stirring. The hydration equilibrium of the starch and proteins in dough may be upset enough to affect the volume of the product baked from the dough. It would be interesting to see the results of studies on the effect of freezing dough protein and starch.

Although frozen dough can be stored for only short periods, the baked frozen rolls can be stored longer. Fenton (69) reports that baked frozen rolls, heated immediately after removal from the freezer, were excellent even after 12 months' storage.

Frozen Batter Products and Frozen Cake

Several studies by students indicate baking powder biscuits (rolled, cut, and ready to bake) can be frozen and stored for a limited time, 2–3 weeks. There was little difference in the baked product whether the baking of the dough was started after or before thawing. However, the striking result of each study was that the portion of the dough baked immediately after mixing had better volume, higher palatability scores, and was more tender than the portion of the dough that was frozen and then baked. The drop in quality came as soon as the dough was frozen (first tests were after overnight storage), which may indicate that the damage may be brought about by freezing per se, for baking powder biscuits contain no yeast. Biscuits can be successfully frozen after baking, but few persons would want to serve warmed over frozen biscuits.

Acceptable muffins were obtained by freezing the batter in Pyrex or paper cups or muffin pans. Here again the freshly baked batter was preferable to that which was frozen and then baked.

Several studies have been reported on freezing cake (75, 76, 77, 78, 79, 80, 81, 84). As would be expected, there was not agreement on all points in these studies. But; the different groups of investigators did not use the same formula, the ingredients were obtained from different sources, the time in frozen storage varied, and sometimes the freezer storage temperatures varied. Both the volume of the frozen cake and the cake baked from the frozen batter was smaller than that of the freshly baked controls in three studies (76, 78, 84), one exception being a batter made with S.-P. baking powder and lard (84). A very decided decrease in the volume of the cake from the frozen batter was found in two studies (77, 80), whereas no significant difference was found among volumes of fresh, frozen baked, and baked frozen batters in one study (84). Cakes and batters retained their palatability for longer periods of time at lower storage temperatures than at higher ones (76, 77). In some studies cakes made with butter kept better than those made with hydrogenated shortening or lard (76, 77) and in one study the cakes containing the hydrogenated vegetable oil kept better than those made with lard (84). Off flavors appeared at varying times. Some of the factors affecting the results in freezing batter and dough products are: (*a*) the time and temperature of storage, (*b*) the *p*H of the product, (*c*) the ingredients and their proportion, and (*d*) possibly the freezing.

Time and temperature of storage. In general, the deteriorative changes become greater as the storage period is lengthened. Cakes and batters (76) held at −18°C deteriorated more rapidly than those held at −23°C. The temperature of the home freezer fluctuated in some studies.

***p*H.** As the batter becomes more alkaline some reactions are intensified. Among these are the browning reaction. Fat hydrolysis is also speeded. Water balance of the protein is affected by the *p*H.

The ingredients. The same ingredient may vary from time to time and affect results obtained in various tests. To illustrate: pastry made from a hydrogenated vegetable shortening became rancid in frozen storage in 1 week. Pastry made from another can of the same brand of shortening and used in the same study kept as long as the experiment was run.

The flour. Flour contains peroxidase, lipase, amylase, and proteolytic enzymes which act as catalysts to certain reactions over a long period of time. These reactions would be inhibited by baking the batter. The flavor changes in frozen sponge cake batters, but not in the frozen cakes, observed by Meyer et al. (78, 79) may illustrate this point. The off flavors may have been accelerated by enzymes. Unbleached flour has better antioxidant properties than bleached flour (74).

Shortening. Lard is notably low in natural antioxidants. Antioxidants improve its keeping quality. Butters may vary; some have more lecithin than others, which is a fair antioxidant for animal fats (74). Hydrogenated vegetable shortenings are made from soybean, cottonseed, and peanut oils. These are listed in order of descending production. The manufacturer uses any or a combination of these oils, depending on the source of supply, price differential, and order specifications. When soybean oil is hydrogenated it may develop an off flavor on storage. This may be the explanation of some of the poor keeping qualities of the frozen cakes and batters made from hydrogenated vegetable oils. Some ingredients used in cake are efficient antioxidants.

Baking powder. Tartrate baking powder reacts slowly at low temperatures so that batters containing it would be expected to have smaller volumes after frozen storage than similar cakes made from slower reacting powders. If sodium aluminum sulfate reacts the same in frozen batters as in mixes (74), it accelerates rancidity and toughens the gluten. The last may in part account for the decreased tenderness and volume in frozen biscuits when the baking powder contains this ingredient. Watts et al. (83) found that the residues of baking powders inhibited rancidity in artificial fat-aqueous systems in the following order: sulfate-phosphate, tartrate, monocalcium phosphate, and pyrophosphate, the sulfate-phosphate being the least effective and the pyrophosphate far more effective than the other types.

Eggs. Meyer et al. (79) suggest that the flavor deterioration observed in cakes baked from frozen batters is caused by the oxidation of the egg-yolk lipids during freezer storage. The flavor deterioration and peroxide formation were proportional to the concentration of egg yolk in the batters (cakes were made of whites, whole egg, and egg yolks). No off flavor developed in the cakes baked before freezing. Addition of an antioxidant or lemon juice to the batter delayed the development of the off flavor.

Vanilla. Vanilla, either synthetic or natural, contains an aldehyde group. This can react with an amino group to form a carbohydrate-protein complex with a brownish color (76), if other conditions such as *p*H, moisture, etc., are right.

Denaturation and other factors. It is known that freezing denatures casein of concentrated skim milk (82), which results in the appearance of insoluble curdy particles. Very low temperatures and the addition of sugar tend to prevent the denaturation. If the gluten proteins are partially or wholly denatured by freezing this would affect the extensibility of the proteins. In turn this may, in part at least, account for the decreased volume in biscuits, muffins, and rolls made from frozen batter or dough. Since freezing forms ice crystals, the withdrawing of water from proteins and starch may upset the moisture equilibrium in the dough and result in damage.

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CHAPTER
5

Fruits and Vegetables

Cooking Vegetables

Vegetables, for cooking purposes, may be classified in various ways. One classification is to group them according to color, although more than one pigment is often found in the same fruit or vegetable. Chlorophyll is accompanied by carotenoids, and the flavones are almost universally distributed. A second classification is to group vegetables as mild or strong flavored.

Under the first classification are: (*a*) The green vegetables; these include all greens, asparagus, Brussels sprouts, green cabbage, green snap beans, and others. (*b*) The yellow or orange vegetables; these include carrots, squash, sweet potatoes, and rutabagas. (*c*) The red vegetables; the most common are beets and red cabbage. The pigment of the red tomatoes belongs to the carotenoid family. (*d*) The white vegetables; these include cauliflower, turnips, potatoes, and white onions.

There may not be agreement on what constitutes mild- or strong-flavored vegetables. Some vegetables develop strong rather disagreeable flavors upon cooking; others such as onions increase in mildness with longer cooking. The author would include turnips, rutabagas, and the brassicaceous vegetables, cabbage, broccoli, Brussels sprouts, and cauliflower in the list of these developing strong flavors with cooking or with overcooking. Depending on whether they are liked or disliked, other vegetables such as spinach and asparagus may be added to the list of strong-flavored vegetables. Vegetables, other than those listed above, used in this and other countries may be fitted into the classifications according to their characteristics.

Methods of cooking. Vegetables are commonly cooked in saucepans or kettles (covered or uncovered), pressure saucepans, waterless cookers, and, particularly for institutional use, in steamers.

Palatability of vegetables. Many studies have been reported in the literature on retention of nutritive constituents when the vegetables are cooked by various methods. In a few of them the palatability of the vegetable was also determined, and in a few studies only the palatability was determined (1, 3, 5, 6, 7, 8). The results of these studies are difficult to summarize. This is understandable. All the cooking methods were not used in each study. The amount of water left at the end of the cooking period was not standardized for the different studies. The same vegetables were not used in all studies. Some vegetables tested during more than one season did not behave alike in different seasons, and the same vegetable used in different studies did not always respond alike. Some vegetables were purchased on the open market; some were raised and harvested on experiment station plots.

The palatability of the vegetables decreased when they were overcooked (8). Steamed kale was less palatable than that cooked in an open kettle when 4 varieties were cooked through 5 growing seasons (3). Peas cooked in a kettle and in a dielectric range were about equally acceptable (5).

In general, mild-flavored vegetables were equally acceptable cooked in an open kettle or in a pressure saucepan, and stronger-flavored ones were preferred when cooked in the kettle to those cooked in a pressure saucepan (1, 6, 8). There were some exceptions to this generalization. When broccoli and frozen peas were cooked at 0-, 5-, 10-, and 15-pounds pressure, with the amount of water approximately the same at the end of the cooking, the different pressures did not produce significant differences in the palatability of the cooked vegetables. The total cooking time for the broccoli (including time to bring to pressure desired) was about 13, 7, 6, and 5.5 minutes, respectively (7).

In studies in the author's laboratory in which the vegetables were cooked in an open kettle with varying amounts of water left at the end of the cooking period, the mild-flavored vegetables were preferred when the amount of water was practically none or very small to those with larger amounts of water.

Variation in quality of vegetables. The quality of vegetables varies with (*a*) variety, (*b*) the growing season, (*c*) climatic conditions, (*d*) stage of maturity, and (*e*) the manner and time of storage before cooking. The time and method of cooking employed may retain or bring about a decrease in the palatability.

Histological changes. Chemical and histological changes in vegetables occurring during cooking are discussed by Simpson and Halliday (4). Weier and Stocking (9) review the literature on histological changes in fruits and vegetables.

Plant Acids

In order to serve cooked vegetables that are attractive in appearance, color, and texture, a knowledge of the common reactions of plant acids, pigments, cellulose, and other constituents is helpful. These reactions are less often considered than the nutritive constituents of plants, for, with the exception of the carotene precursor of vitamin A, they are relatively unimportant nutritionally.

Plant acids. The acids and acid salts found in plants (17, 48) are numerous. Of the various aliphatic and aromatic acids, one aliphatic group is often called "the plant acids." This group is widely distributed in the higher plants and has definite physiological functions. The best known of this group of acids are citric, malic, oxalic, succinic, and tartaric. Bonner (17) states that the less well known of these acids, but probably of equal importance and distribution, are isocitric, *cis*-aconitic, oxaloacetic, and α-ketoglutaric. All of these acids, except oxalic and tartaric, play a role in cellular respiration in the series of reactions known as the Krebs cycle.

In addition to the volatile acids and excluding the aromatic acids, Onslow (48) states that the following acids may also be found in plant tissues: glycolic or hydroxyacetic, malonic, glutaric, adipac, and racemic.

For consideration in cooking, the organic acids in plants may be divided into two classes, volatile and non-volatile. Volatile acids are the ones that pass from the liquid as vapor during cooking. The odor of acetic acid or vinegar when heated is well known. The following acids of the $C_nH_{2n}O_2$ series are volatile, the first ones being more volatile than the last ones:

Formic acid	$H\cdot COOH$
Acetic acid	$CH_3\cdot COOH$
Propionic acid	$CH_3\cdot CH_2\cdot COOH$
Butyric acid	$CH_3\cdot CH_2\cdot CH_2\cdot COOH$
Valeric acid	$CH_3\cdot CH_2\cdot CH_2\cdot CH_2\cdot COOH$
Caproic acid	$CH_3\cdot CH_2\cdot CH_2\cdot CH_2\cdot CH_2\cdot COOH$

Formic and acetic acids have been obtained from plants during distillation. Propionic acid (48) has only rarely been found in plants.

The amount of volatile acids found in different plants varies; it also varies in the same plant. Asparagus, cabbage, cauliflower, and peas were used to determine the comparative quantity of volatile acids evolved during three 5-minute periods. The amount was always greatest for the first 5 minutes of cooking.

Esters of the above acids are responsible for many fruit odors (48). Amyl acetate is found in bananas; amyl formate, acetate, and caproate in apples.

Non-volatile acids. The more common non-volatile acids include those tabulated.

Dicarboxylic acids	
Oxalic	$COOH\cdot COOH$
Succinic	$COOH\cdot CH_2\cdot CH_2\cdot COOH$
Fumaric	$COOH\cdot CH{=}CH\cdot COOH$
Oxaloacetic	$COOH\cdot CH_2\cdot C{=}O\cdot COOH$
α-ketoglutaric	$COOH\cdot CH_2\cdot CH_2\cdot C{=}O\cdot COOH$

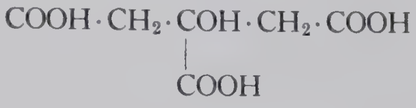
Hydroxydicarboxylic acids

L-malic $COOH \cdot CHOH \cdot CH_2 \cdot COOH$

L-tartaric $COOH \cdot CHOH \cdot CHOH \cdot COOH$

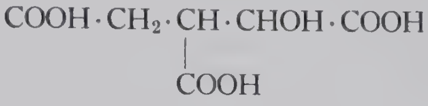
Tricarboxylic acids

Citric



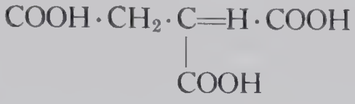
$$\begin{array}{l}COOH \cdot CH_2 \cdot \underset{\displaystyle COOH}{\underset{|}{C}}OH \cdot CH_2 \cdot COOH\end{array}$$

Isocitric



$$COOH \cdot CH_2 \cdot \underset{\displaystyle COOH}{\underset{|}{C}}H \cdot CHOH \cdot COOH$$

Cis-aconitic



$$COOH \cdot CH_2 \cdot \underset{\displaystyle COOH}{\underset{|}{C}}{=}H \cdot COOH$$

The non-volatile acids also escape into the cooking water. This can e demonstrated readily by tasting the water in which fruits have been ooked or for vegetables by determining the pH of the water before and fter cooking. Since the acidity of the vegetables varies, different vegetables ary in the extent to which they alter the pH of the cooking water.

Aromatic acids. These acids are widely distributed. Sometimes they ccur in the free form, such as benzoic acid; sometimes as esters, such as alicylic acid in oil of peppermint; and sometimes as glycosides.

The distribution of plant acids. The acids are found in the leaves, tem, fruits, and rootstock of plants. Bryant and Overell (18) using a uantitative chromatographic method of analysis found that malic was the hief acid of carrots with succinic and fumaric present in appreciable quantities. Three other acids were detected but not identified. The concentration of the different acids varied considerably from carrot to carrot.

Citric acid, according to Bonner (17), is of universal or nearly universal distribution in plant tissues. It is found in high concentration in he edible portions of citrus fruits. It is also the chief acid (14, 21, 47) n cranberries, currants, gooseberries, guavas, loganberries, raspberries, trawberries, and tomatoes.

Of the 4-carbon plant acids, Bonner (17) states malic acid is ubiquitous n its distribution. It is the principal acid of apples, bananas, cherries, hubarb, and pears.

Succinic and fumaric acids are widely distributed. Benzoic acid is found n cranberries, plums, and prunes. Fermented fruit juices always contain cetic acid. Charley (21) reports traces of formic, caproic, and caprylic cids in fermented apple juice.

Because of oxaluria the oxalic acid content of vegetables is of interest. xalic acid occurs widely distributed in plants, usually as the calcium salt 17, 48). It is found in large quantity in the rumex or dock family, of hich different docks and sour grass are used for food. Sorrel and rhubarb ontain a rather high percentage. Spinach (52) contains 0.486–0.692%

of oxalic acid; beet greens contain similar or slightly higher amounts; and, New Zealand spinach a still higher percentage (52). No oxalic acid was found in dandelion greens, kale, turnip greens, or mustard greens.

Total acidity. The total acidity of most fruits varies with the degree of ripeness (47). The relative proportions of the various acids may also vary with the degree of ripeness, variety, and climatic and soil conditions.

Mineral salts of organic acids. Mineral salts of organic acids may be formed when fruit or fruit products stand in certain metal containers or when fruits are cooked in metal containers. Very unpalatable flavors are developed in this way, and the color of the cooked product is darkened. This brings to memory a sample of plum butter sent to the Department. It was nearly charcoal black in color, and as for flavor might have been made from any fruit, for there was little of the original fruit flavor left. The sender stated it had been cooked on the back of the stove in a tin wash boiler for 3 days and was much perturbed because a neighbor had told her it was poisonous on account of the cooking utensil used.

The tin salts are not poisonous, but they may produce a very dark color and a disagreeable metallic flavor, when certain types of containers are used in the wrong way.

Zinc utensils. Some of the metal salts formed with organic acids are injurious when taken into the body. The zinc salts of organic acids have been regarded as toxic. They are formed when foods containing acids are placed in galvanized containers. Galvanized iron contains some zinc, and when fruits, beverages, or even milk are placed in utensils made of it, the acids of the food combine with the zinc, forming salts.

Sale and Badger (53) have reported that zinc is dissolved from galvanized utensils, and the greater the acidity of the food and the longer the food stays in such containers the more zinc is dissolved. Even fresh milk contains enough acid to dissolve appreciable amounts of zinc.

Burke, Woodson, and Heller (19), after investigating the toxicity of buttermilk held in galvanized containers, question the attributing of the toxicity to zinc in many previous investigations, and think that sometimes the toxicity may have been due to the surface of the galvanized container being contaminated with some other substance, possibly arsenic, lead, or antimony.

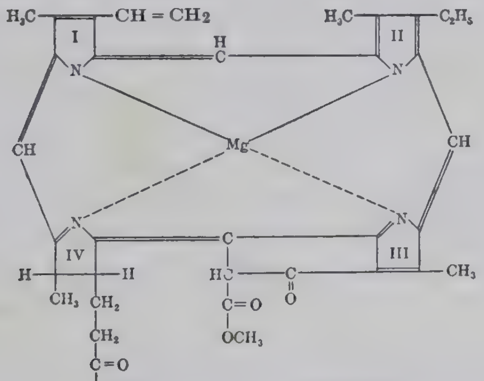
Iron salts with acid may cause discoloration in some food products. Poe and Nyholm (50) have reported the effect of cooking fruit juices in stainless-steel utensils. After 1 hour of cooking, they found the maximum amounts of metals dissolved to be 0.003 gram iron, 0.001 gram chromium, and less than 0.00002 gram nickel per kilogram of food. They believe that the amounts of chromium and nickel are too small to have any detrimental physiological effect.

Plant Pigments

Plant pigments include the water-insoluble plastid pigments—the chlorophylls and carotenoids—and the cell-sap-soluble pigments—the anthocyanins, flavones, flavonols, and similar substances. These pigments may change in color as the result of a change in physical state, or of chemical reaction with metals, metallic salts, acids, alkalies, oxygen, etc. They vary in stability, in rate of reaction, and in the nature of the products formed from them.

Chlorophyll. The several chlorophylls (10) have an important role (17, 26, 30, 48) in the process of photosynthesis in plants. Carbohydrates are formed in the presence of light in green plants. The cells of the mesophyll of the leaf contain chloroplasts, the nucleus, other substances, and the cell liquid with its dissolved materials. The chloroplasts (48) contain 4 pigments: 2 green ones, chlorophyll *a* and chlorophyll *b;* and 2 yellow ones, carotene and xanthophyll. There are 2 to 3 parts of chlorophyll *a* to 1 part of *b*. The structure of chlorophyll is very similar to that of hemin of hemoglobin, indicating a close relationship between these 2 important pigments.

Structure of chlorophyll. Willstätter (61) gave us the formula for chlorophyll. It contains 2.7% of magnesium and has two ester groups, one of methyl alcohol (CH_3OH) and one of phytol alcohol ($C_{20}H_{39}OH$). One of the two formulas proposed by Fischer (25) for chlorophyll *a* is:



Chlorophyll *a*

The other formula proposed by Fischer (25) differs in the position of the double bonds. MacKinney (43) states that the probability of resonance in the double bonds excludes the establishment of a fixed pattern for these.

Chlorophyll *b* contains a formyl group in place of the methyl group on ring II.

Solubility of chlorophyll. Chlorophyll is not soluble in water. Very little green color is found in the water in which green vegetables have been cooked. Pure isolated chlorophyll is soluble in acetone, ether, and benzene. In extracting the pigment from thoroughly dry leaves it is necessary to add about 20% of water to the acetone or other solvent. One explanation for this is that chlorophyll is in the colloidal state in the leaf, and the mineral constituents of the leaf, dissolved in the water, peptize it, rendering it soluble. When green vegetables are dropped into boiling water a change takes place nearly instantly, the green color being intensified. Various explanations have been offered for the phenomenon. Onslow (48) states that "the condition of chlorophyll is altered by plunging into boiling water. The pigment is then much more soluble, in ether, etc., even when the leaves are subsequently dried. It is supposed that the chlorophyll has diffused out from the plastids, and is in true solution in the accompanying waxy substances which have become liquid owing to change in temperature." Another theory is that the hot water may have dissolved salts or other substances in contact with the chlorophyll so that it diffuses more readily. A third explanation is that chlorophyll occurs naturally in a protein complex. The heat coagulates the protein, leaving the pigment more soluble. It has also been suggested that chlorophyll is present in leaves in two phases, one bound to protein, and one dissolved in lipids (10).

Reactions of chlorophyll with alkalies. Chlorophyll is a neutral substance but gives characteristic reactions when treated with alkalies or acids. Alkalies cause the hydrolysis of the ester linkages, removing the methyl and phytol alcohol groups. The color changes first to brown, then becomes intensely green, but the pigment is no longer fluorescent.

When green-colored vegetables are cooked in water with an alkaline reaction, or in water to which a small amount of soda is added, they develop a bright, intense green color. However, the addition of soda is not advisable, as it softens the cellulose rapidly so that the vegetable becomes mushy or even slimy. Also, the destruction of some of the vitamins is greatly increased.

Reactions of chlorophyll with acids. Chlorophyll reacts with acids to give an olive-colored product, without fluorescence, called pheophytin, in which the magnesium of the chlorophyll is replaced by hydrogen.

The effect of heat upon chlorophyll. Heat decomposes chlorophyll. The extent of decomposition depends on the time and temperature of heating, the rate of color change increasing with increase in time and temperature of heating. The degradation products are a dull yellow-green, about the color of processed green olives.

Vegetables contain both volatile and non-volatile acids. In the raw vegetable these acids are not in contact with the chlorophyll, but during the cooking process the acids are liberated and cause the development of the olive-green color. Most of the volatile acids are carried off in the steam if the vegetable is cooked uncovered. As this loss of acid is greatest during the first few minutes of cooking, if it is necessary to cover the vegetable for part of the cooking period, it should be the latter part.

The non-volatile acids may be neutralized, to a certain extent, by the cooking water. Hard water, softened water, or water from many streams is alkaline in reaction. Rain water, snow, or ice water is usually about neutral. If the cooking water contains alkaline salts, they may be sufficient to neutralize the plant acids. This will be determined by the amount of alkaline salts present in the water and by the amount of water used. In some cases the alkalinity of the water may be high enough to intensify the green color. However, with longer cooking, the heat may have more effect than the alkalinity on the chlorophyll.

Canned green vegetables such as spinach, asparagus, peas, and string beans develop a deep olive-green color as the result of the retention of plant acids in the sealed can and the high temperatures used for processing. Cooking in a pressure cooker has much the same effect.

Green vegetables such as cabbage and Brussels sprouts may retain a bright green color when cooked in milk, as milk scorches so easily that there is little tendency to overcook the vegetables.

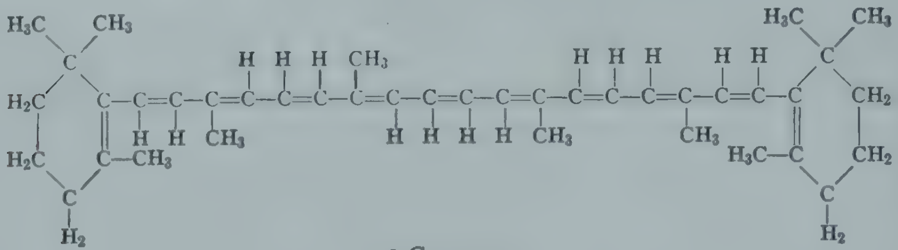
Green vegetables that contain enough acid to taste sour, like sorrel, sour grass, and dock, always become an olive-green color no matter how they are cooked or for how short a time. Their acid content is too high to be neutralized by the alkaline salts of water or the addition of baking soda in small amounts. Green fruits like gooseberries, green grapes, and green plums also develop an olive-green color when cooked. However, if the fruits are mature they may contain yellow pigments which modify the color to some extent.

If acid is to be added as a seasoning to green vegetables, it is preferable to add it just before serving, for there will be less time for the acid to react with the chlorophyll, and less brown color will develop. When vegetables are cooked with added acid, the softening of the vegetable is prevented to a slight extent.

Blair (16) reports a method of retaining the bright green color in canned vegetables. The vegetable is soaked in NaCl solution for 3 hours, blanched in $Ca(OH)_2$ brine to prevent rupture or softening of the tissue, and canned in a brine containing sufficient $Mg(OH)_2$ to preserve the alkaline balance.

Replacing magnesium in chlorophyll products. It is very difficult to put the magnesium back into the chlorophyll molecule once it has been removed. It can be done chemically by means of a very reactive substance, magnesium methyl iodide, but this is impracticable for use in cooking processes. However, Willstätter (61) states that the acetate salts of metals such as copper, iron, and zinc will combine with pheophytin to give very bright green-colored products. This may be demonstrated in the laboratory by adding copper acetate to green vegetables in which the olive-green color has been developed by the addition of acid. On standing, a vivid green color will develop.

Carotenoids. The carotenoids are insoluble in water, but soluble in fats. They are pigments which give an orange, yellow, or, in tomatoes, the red color to fruits and vegetables. Karrer and Jucker (35) state that about 80 carotenoids have been found in nature. The carotenoids are divided into two groups, the carotenes and the xanthophylls. The xanthophylls are oxygen-containing derivatives of carotene. β-carotene, one of the best-known members of this class, yields 2 molecules of vitamin A upon oxidative splitting of the molecule at the center. It has the formula as shown (from Bogert in Gilman's *Organic Chemistry*).

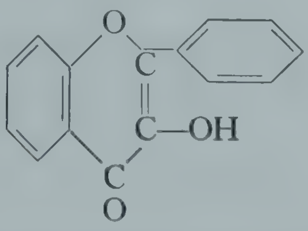


β-Carotene

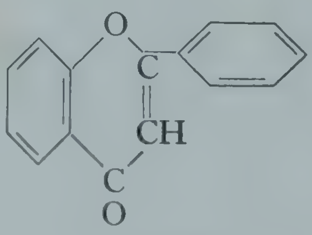
Lycopene, the principal pigment in red tomatoes, is an isomer of carotene. The formula has been elucidated by Karrer (35) and the pigment is said to be more widely distributed in nature than was formerly believed.

The carotenoids are not affected, to any great extent, by the concentration of acid or alkalies used in food preparation. The darkening produced by caramelization of sugar in vegetables like carrots, during cooking, must not be confused with a change in the pigment color. Carotene and xanthophyll are easily oxidized when exposed to air.

Flavones and flavonols. Crystalline flavones and flavonols are yellow pigments. They are widely distributed in plants. Flavones and flavonols usually occur as glycosides (30, 48). In this state they are pale in color and readily soluble in water. Upon hydrolysis the pigment becomes insoluble in water but becomes soluble in organic solvents. They are also found in the cell sap of the epidermis and underlying tissue of plants. The basic formulas are shown.



Flavonol (2-phenyl benzopyrone)



Flavone

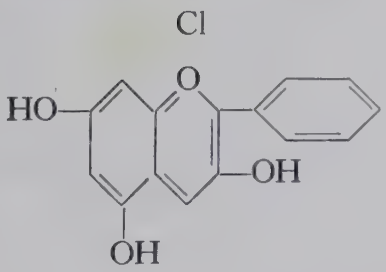
The other pigments of this group differ from flavone and flavonol in the number and position of the groups attached to the basic molecule. These are mostly water-soluble yellow pigments stable to acid but made intensely yellow by treatment with alkali. They may occur as glycosides, uncombined or in association with tannins. Sometimes the quantity of them found in white vegetables is so minute that they are not visible. Adding an alkali or holding the vegetable over ammonia vapor intensifies the color, and the pigment becomes visible. The color changes of the flavones cannot be observed so readily in yellow, red, or green vegetables.

Rice cooked in alkaline water usually has a yellow tinge; sometimes it turns green. Rice from the same source, cooked in distilled water, has a snow-white appearance.

The cooking of cauliflower, white cabbage, and particularly white onions in alkaline water often causes development of yellow color. Some white onions cooked in the hard water at Ames have become nearly sulfur yellow, whereas portions of the same onions cooked in distilled water remained white or retained their natural light yellow tinge. Sometimes potatoes also develop a yellow or green color in alkaline water.

Iron salts turn flavones and flavonols green and then brown. This may explain some color changes that occur when foods are cooked in chipped enamel utensils having an iron base. Tin forms color-stable complexes with these pigments.

Anthocyanins. The anthocyans occur as glucosides in different parts of the plant and are known as anthocyanins in this combination (17, 26, 28, 30, 48). When the glucoside is hydrolyzed with acid, alkali, or enzyme, the sugar and an aglycon or sugar-free residue is obtained. This sugar-free residue is known as anthocyanidin. The anthocyanidins are divided into three main groups: the pelargonidin, cyanidin, and delphinidin pigments. These anthocyanidins vary in the number of phenolic hydroxyl groups on the 2-phenyl ring. Further variations are brought about by methylation of the phenolic hydroxyl groups. Bonner (17) states that a variety of sugars may be involved in the glucoside combination. In addition, mono- and diglycosides, as well as mixed diglycosides, may occur, so that a variety of anthocyanins are derived from the anthocyanidins. The basic nucleus of the anthocyanidins, according to Gilman's *Organic Chemistry,* is 3,5,7-tri-hydroxyflavylium chloride. The anthocyanins are usually extracted as the chlorides, but in the plant they may be combined with other anions. The close structural relationship between anthocyanidins and flavones is readily apparent.



Color. The anthocyanidins are amphoteric, water-soluble pigments. They impart the blue, purple, violet, and red shades to different parts of the plant. They are widely distributed, occurring in apples, blueberries, cherries, currants, grapes, red and black raspberries, some varieties of peaches, plums, red cabbage, radishes, beets, as well as other fruits, vegetables, and, in stems, leaves, and flowers. They change color with hydrogen-ion concentration. In acid solutions pure anthocyanins are usually red; in alkaline they are violet or blue.

Factors affecting the color. The color of the anthocyanins varies with their chemical structure. Thus the pelargonidins, with one phenolic hydroxyl group, are redder than the cyanidins and delphinidins, which contain two and three hydroxyl groups, respectively (17). Methylation increases the redness. Diglycosides tend to be bluer than the monoglycosides. Other pigments, such as tannins and flavones, may affect the color. The *p*H of the cell sap also affects the color. Some flowers are pink when first opened with slightly acid *p*H and then turn blue, the *p*H becoming more alkaline during this process (17). Salts, especially iron and tin, may also influence the color.

Color changes of fruit juices. The solutions of many fruit juices show the typical anthocyanin color changes. In ordinary plant pigments, they may become green, then yellow, and sometimes brown upon the addition of alkali. If the addition is faintly alkaline, a blue color may form and the green may never develop. Pratt and Swartout (51) found that some fruit juices can be used as indicators in titrating acids, but not bases, for they decompose in a more alkaline solution and become brown. They found that apricots, peaches, pears, persimmons, and tomatoes failed to yield pigments that could be used as indicators. It is interesting that the pigment of cactus holds its red color even in a distinctly alkaline medium. They also state that "the pigment of red beets remained red through the acid range and into the alkaline range at least as far as *p*H 13.0." In their conclusion they recommend that the greatest usefulness of the indicators is in test papers.

These authors have indicated the color of many fruit juices in neutral, acid, and alkaline medium. See Table 13.

TABLE 13

THE COLOR OF FRUIT JUICES IN NEUTRAL, ACID, AND ALKALINE MEDIUMS
(*Pratt and Swartout*)

Fruit source	Neutral tint	Acid tint	Alkaline tint
Apples	Grayish purple	Red	Green
Blackberries	Purple	Red	Bluish green
Blueberries	Purple	Red	Blue
Cherries	Reddish purple	Red	Bluish green
Cranberries	Faint purple	Red	Light green
Grapes	Purple	Red	Bluish green
Plums	Faint purple	Red	Light green
Pomegranates	Purple	Red	Bluish green
Strawberries	Reddish purple	Red	Light green

Combinations of fruit juices. The color of combinations of fruit juices may vary. For a red color, red or blue-colored juices are used and the reaction is kept acid by addition of lemon juice. For a purple shade, fruit juices nearly neutral in reaction are chosen, and the lemon juice is omitted. A blue color can usually be intensified by adding canned pineapple juice. Whether water affects the color of the juice depends on the alkalinity of the water and the acidity of the juice. Red and yellow, blue and yellow, or green and yellow combinations usually do not produce attractive colors.

The color change obtained by the addition of canned pineapple juice to grape, wild grape, blackberry, raspberry, or loganberry juices cannot be explained on the basis of hydrogen-ion concentration. Even if these juices are acidified with large amounts of lemon juice they usually turn blue after the juices are mixed and left standing. Tin salts from the canned pineapple may be a cause for the color change. Many anthocyanin salts have characteristic colors which are independent of small changes in acidity. In addition, the presence of other substances such as proteins, tannins, or metal salts may alter the color.

Color changes of red vegetables. Reports vary as to the pH at which red cabbage extract turns blue. Usually at a pH of 2.4 to 4.0 the color is red, showing gradual changes through red, purple or violet, red-blue, and finally blue. These changes occur over a wide range of pH, the blue developing at pH 6 or at 7 to 9. With still higher concentrations of alkali, it may become green, yellow, and then brown. An acid or salad dressing added to red cabbage intensifies the red color. When the cut edges of red cabbage come in contact with hands or knives they turn blue. Hands and knives washed in hard water or with soap may have salts with an alkaline reaction on the surface. The anthocyanins may also form compounds with iron salts.

Red onions show the same color changes as red cabbage, but the colors are often muddy.

Beets do not develop the blue or green color. Sometimes they turn from red to yellow when cooked. If they are placed in acid, the red color is usually restored. Blair (15) states that beets contain two pigments, one scarlet and one purple. The scarlet pigment is stable to heat, but the purple one fades. He found the scarlet pigment to be stable at pH 9. Pratt et al. (51) found it to be stable at pH 13.

Anthocyanin pigments and food processing. The color of canned or cooked beets depends on the proportion of scarlet and purple pigments present. Beets are now produced in which the scarlet pigment has been increased by breeding. Culpepper and Caldwell (23) have reported that anthocyanin pigments combine with tin, forming violet-colored salts. They found high acidity tends to prevent, whereas low acidity favors, the production of the violet color.

Lathrop (42) states that both iron and tin are "injurious to fruit pigments. The compounds of the pigments with the metals become quickly oxidized on exposure to air, with a marked increase in intensity of discoloration. Tin turns grapes, cherries, raspberries, and blackberries a deep purple and strawberries a pale red. Iron produces dull brownish discolorations. Copper and aluminum are far less injurious and are therefore used wherever fruit must come in contact with metal. Copper being somewhat injurious to the color of grape, aluminum is usually used with grape."

Sondheimer and Kertesz (57) observed an indirect ascorbic acid-induced destruction of the anthocyanin pelargonidin 3-monoglucoside of strawberries. Conditions that delayed the destruction of ascorbic acid also delayed the destruction of anthocyanins.

Tannins

The term tannin is sometimes used to denote a whole group of substances having certain characteristics in common. Sometimes it denotes a particular substance, *e.g.,* gallotannic or digallic acid. The former is the meaning used in the following paragraphs.

The tannins are widely distributed in the higher plants. Some plants are very rich in them; others contain very little. The amount in the plant varies with different years and growing conditions. The tannins are found throughout the plant, but the woody part, the stems, and rootstocks are likely to contain larger amounts. They are found in many fruits, especially during the immature or green stages, and in the seeds of several plants. Lathrop states that stemming of grapes prior to heating for juice extraction is advisable to get rid of astringent tannin of the stems which would be detrimental to flavor.

To some extent the tannin content of fruit is dependent not only upon environmental influences, but also upon inherited characteristics. The New York Experiment Station has reported a variety of peach called Sunbeam, which does not turn brown when pared. Kertesz (36) reports its tannin content as very low, 0.0076%.

Reactions of the tannins. Thatcher (60) states that chemically the "tannins are either free phenol-acids, or, more commonly, glucosides of these acids." The structure of the tannins is very similar to that of the anthocyan pigments. They are divided into two general classes, known as the pyrogallol tannins and the catechol tannins. Thatcher has reported the following characteristic reactions.

	PYROGALLOL VARIETY	CATECHOL VARIETY
Ferric salts	Dark blue	Greenish black
Bromine water	No precipitate	Yellow or brown precipitate
Leather	Produces bloom	No bloom
Concentrated sulfuric acid	Yellow or brown	Red or pink
$Ca(OH)_2$	Gray or blue precipitate	Pink or brown precipitate

Haas and Hill (29) summarize the properties of the tannins under eight headings. Only five will be given here.

1. Tannins are mostly uncrystallizable colloidal substances with astringent properties.
2. They give blackish blue or blackish green colors with ferric salts, a fact utilized in the manufacture of ink.
3. In alkaline solution the tannins and many of their derivatives readily absorb oxygen, becoming dark in color.
4. They precipitate gelatin from solution and form insoluble compounds with gelatin-yielding tissues, a property which enables them to convert hide into leather.
5. They are precipitated from solution by many metallic salts such as copper or lead acetate or stannous chloride.

Astringent qualities due to tannins. The astringent properties give a slightly bitter taste to some foods, the degree depending on the amount of tannins present. Thatcher states, "Tannins are of frequent occurrence in green fruits imparting to them their characteristic taste. They nearly always disappear as the fruit ripens." Two explanations are suggested for the disappearance of the tannins in ripening fruit. The anthocyan pigments may be derived from the tannins, so that as the fruit colors the tannins disappear; or the tannins may be changed into an insoluble form and therefore are not so apparent to the taste.

Persimmons contain a very large amount of tannin. Green persimmons have a bitter, astringent, puckery taste that is not easily forgotten, once they have been tasted. Gore's work (27) has shown that most of the tannin of persimmons is enclosed in cells, which he terms giant tannin cells. By artificial processing in CO_2, or by ripening, the membrane containing the tannins becomes hard and insoluble so that the astringent taste is not evident.

Blue or purple discoloration in English walnuts. English walnuts are more astringent than other nuts and often change color unattractively when combined with other foods. When they are combined with apples in a salad they often develop a blackish blue or purple color. This may come from having prepared the apples with an iron knife, the acid and enzyme of the fruit acting on the iron to produce ferric salts. When this small amount of ferric salt comes in contact with the tannin of the nut and particularly with the skin the purplish color develops. In nut bread, English walnuts often produce a dark color.

Tannins may produce a gray shade in sugar. Zerban (62) has found that the color of dark greenish cane juice, which produces a sugar with a gray shade, may be due to tannins, oxidizing enzymes, and iron. When the cane is crushed the acid of the juice forms some ferrous salts with the iron of the roller. Oxidizing enzymes of the juice oxidize the ferrous salts to ferric ones, and they combine with the tannins of the juice.

A similar change occurs when fruits are pared with iron knives and especially when the juice is left to stand on the knife and it darkens.

Tannins and discolorations in canned foods. Kohman (39) has reported that the dark spots often found in canned sweet potatoes are due to tannins which combine with the iron of the can. Oxygen is necessary to oxidize the ferrous iron to ferric, so that, unless oxygen is present in the can, the discoloration does not occur. Asparagus canned in unlacquered tin cans sometimes darkens when opened and exposed to the air because of oxidation of ferrous to ferric salts. If asparagus is canned in unlacquered tin a small amount of tin dissolves, producing stannous salts which are good reducing agents and prevent the oxidation of the ferrous salts. However, if the water used in canning contains much iron, sufficient tin may not dissolve to prevent the discoloration.

Other discolorations with tannins. Salsify probably contains large amounts of tannic substances. It turns dark when peeled even if put under water unless a little vinegar is added to the water to acidify it. Salsify or oyster plant and sometimes other vegetables such as carrots stain the fingers when they are pared. This may be due in part to tannins. Lemon juice is effective in removing or lightening such stains because of its acidity.

Brownish or black discolorations of vegetables in vinegar have been caused by the tannin of the vinegar combining with the iron of the food. The use of a tannin-free vinegar does away with this difficulty. Greenish black spots in chocolate ice cream have been traced to the tannin supplied by the chocolate or cocoa and the iron from rusty spots in the can. In green-colored beer the iron came from exposed pipes, the tannin from the hops.

According to Atwater (11), cherry juice, now commercially marketed, when mixed with gelatin for a molded dessert, sometimes gave a gummy, purplish precipitate, caused by combination of the tannin of the juice with the protein, gelatin; the purplish color came from combination with metals.

The darkening of mushrooms when peeled is due to reaction between the catechol compounds and the polyphenol oxidase when exposed to air.

A green discoloration in coffee frosting of the 7-minute type sometimes occurs. According to Knowlton (38), this is due to the reaction between the tannins of the coffee and iron from the egg beater or pan. The alkalinity of the egg white favors the reaction. Addition of a small amount of acid-reacting substance such as cream of tartar prevents this color change.

Morris and Bryan (46) report that strawberries are most sensitive, raspberries next, and black currants least sensitive, to discoloration due to iron. The iron affects the tannins or related substances derived from the seed coats and other solid portions of the fruits. The discoloration is intensified by heating and by reduction in acidity.

Discoloration of pared fruit, considered at greater length in the next section, is caused by tannin compounds in combination with enzyme action.

Tea. Black tea is darker than green tea because of oxidation of tannins in the leaf during drying and fermentation. It is also less astringent than green tea because the tannins are in a less-soluble form.

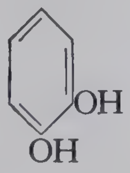
Tannins also give precipitates of calcium, magnesium, and iron tannates, when these minerals are present in the water. The film on coffee or tea is from these tannates. When lemon or orange is added to tea, the film usually disappears, for in acid the tannins often lose the darker color acquired in an alkaline medium.

Tannins lower the surface tension of water, and the water in which vegetables containing tannins are cooked is likely to froth or foam.

Enzymes

Enzymes control many of the complex processes of plant metabolism. A large number of the enzymes are hydrolytic and include the proteinases, lipases, and amylases; but there are also oxidizing and reducing enzymes and other groups of enzymes. Some of the plant enzymes that digest proteins are of interest in cookery. An enzyme of the pitcher plant hydrolyzes fibrin. Bromelin of pineapple acts on native proteins, its effect being more often noticed in cookery when uncooked pineapple is added to gelatin, which is liquefied. Papain of the pawpaw leaf acts on native proteins.

Oxidizing enzymes. Joslyn (33) and Joslyn and Ponting (34) have reviewed the enzymatic browning of fruits and fruit products. The oxidizing enzymes are concerned with the processes of oxidation and reduction in plant cells. Onslow (48) lists the following oxidizing and reducing enzymes: (*a*) Peroxidases, practically always present in higher plant tissue. They decompose H_2O_2 to water and "active" or atomic oxygen. (*b*) Oxidases (laccases or phenolases), present in about 63% of the higher plants. Onslow divides the oxidases into three groups, an oxygenase, an aromatic substance containing an ortho-dihydroxy grouping



Catechol

as in catechol, and a peroxidase. (*c*) Tyrosinase, widely distributed in plants. Through a series of reactions it produces black pigments known as melanins. (*d*) Reductases, which catalyze the decomposition of water into hydrogen and oxygen, provided substances are present which will accept the hydrogen and oxygen. (*e*) Catalase, probably present in all plants.

Joslyn and Ponting (34) cite the grouping of polyphenol oxidases into three groups: tyrosinase, catecholase, and laccase. They state there is still disagreement in the literature on the nomenclature of polyphenol oxidase. Terms used are polyphenol oxidase, catechol oxidase, tyrosinase, and oxidase. They prefer the term polyphenol oxidase and abbreviate it to polyphenolase or phenolase. They state that there are many enzymes that have the ability to catalyze the oxidation of phenols by molecular oxygen. The concentration of polyphenols varies in different fruits, may vary in different parts of the same fruit such as apricots, and in different parts of the same plant as in the leaves and fruit.

The fruits and vegetables that do not brown when injured include citrus fruits, raspberries, blackberries, pineapple, melon, and tomatoes; those that brown readily include apples, apricots, cherries, figs, grapes, mulberries, peaches, pears, plums, potatoes, and strawberries. Zerban (62) found that the polyphenols in cane juice may be oxidized to a brown color, and to a less extent tyrosine may be oxidized to give a dark color.

Browning does not occur in the intact, uninjured cells. The mechanism of browning is not known in detail, probably because so many factors are interrelated. The flavone and anthocyan pigments may be involved, as many of them show the brown reactions of tannins, since they may have the *o*-dihydroxy grouping of catechol. Tyrosine may also be involved.

Prevention of browning. Browning of sliced apples, peaches, potatoes, and other foods may be slowed or prevented by (*a*) changing from the optimum conditions for activity of the enzyme, (*b*) addition of reducing substances, (*c*) removal of the oxygen, (*d*) preventing the oxygen from coming in contact with the food, and (*e*) destroying the enzymes.

pH, temperature. There are an optimum *p*H and temperature, as well as other conditions, for the reaction of each enzyme. Thus the slowing of the browning by dipping fruit for salads into lemon juice, may be partly due to changing the *p*H from the optimum for the reaction of the enzyme. Hydrochloric acid is more effective in preventing browning than citric or tartaric acids. Freezing tends to delay the development of the brown color.

Use of reducing substances or inhibitors. It has long been known that SO_2 prevents darkening of cut surfaces of fruits. It is used for dried apricots, peaches, pears, figs, and for frozen apple slices. It is also used with some vegetables to prevent the development of a brown color in the dried product. Stannous salts as well as sulfites are good reducing substances. Joslyn and Marsh (32) found that orange juice does not brown at high or low temperatures when stored in tin cans. The reducing action of stannous salts prevents the discoloration. However, after the sulfites or stannous salts are oxidized browning can occur. Joslyn and Marsh found that the addition of ferrous salts in concentrations of 25 ppm to the orange juice increased the browning. Ferrous salts were more effective than ferric salts. Nickel, copper, or stannic salts were without effect, whereas the addition of aniline or tryptophan caused immediate browning. Salt and other chloride salts will stop browning temporarily.

The sulfhydryl compounds (12), some of which occur in common foods, inhibit browning. Pineapple juice contains a sulfhydryl compound which inhibits the darkening. Glutathione and cysteine in very dilute concentration prevent darkening of sliced apples.

Ascorbic acid is also used with frozen peaches and other fruits to aid in prevention of enzymatic browning.

Removal of oxygen. This is done in vacuum packing of food products or by replacement of air with CO_2 or nitrogen.

Preventing oxygen from coming into contact with the food. Pared potatoes are often placed under water for temporary storage. Sugar or sugar solutions are added to frozen peaches, apricots, and other fruits. The sugar prevents the oxygen from coming into contact with the fruit, reduces the concentrations of dissolved oxygen, reduces diffusion of oxygen into the fruit, and exerts an inhibiting effect on oxidases (34).

Destroying the enzyme. The cooking of food destroys the activity of the enzymes. Scalding of vegetables before freezing either destroys the action of the enzyme or retards its action sufficiently at low temperature so that the quality of the food product is maintained during freezing.

Cruess, Mrak, and Quinn (22) state that not all the oxidase of peaches is destroyed by blanching at 48.9–71.1°C (120–160°F), thus causing internal browning with the formation of crescent-shaped areas often seen in sliced peaches. To destroy the action of the oxidase of large peach halves requires heating for 10 minutes at 82.2–93.3°C (180–200°F). These investigators state that fruit acids such as citric and tartaric are not so effective as hydrochloric acid in retarding browning. Oxidation was completely held in check by 0.25% of HCl, so that this concentration on the surface of the peach would prevent browning. Salt and other chlorides will check browning temporarily; but, after standing in a 2% salt brine, the fruit must be rinsed to remove the flavor of salt.

Color loss in strawberries. A type of oxidation that causes fading of red fruits in canning is explained by Kohman and Sanborn (41). All fruits and vegetables use oxygen in respiration, and some oxygen is found within the fruit or vegetable. The color of strawberries is deadened if they are heated very rapidly after refrigeration, during which the respiratory processes have been inhibited. However, if they are heated slowly so that the interior oxygen is used in respiration the color remains bright.

Non-enzymatic browning. Stadtman (58) has reviewed the literature on non-enzymatic browning. He states that browning in apricot concentrate is the result of three general types of reactions. The reactions involve (*a*) nitrogenous compounds and sugars, (*b*) organic acids and sugars, and (*c*) nitrogenous compounds and organic acids. (See p. 25.) Variability in browning among different fruits may be caused by the predominating type of reaction, which in turn may be influenced by the composition of the product.

Factors connected with browning of fruits are (*a*) ascorbic acid, (*b*) temperature, (*c*) oxygen, (*d*) moisture, and (*e*) treatment as with SO_2.

These factors are interrelated, and the reference by Stadtman should be consulted for an adequate review.

Browning in orange juice is connected with a decrease in the ascorbic acid content. Stadtman states some investigators think browning is involved with a breakdown of ascorbic acid. In general, the rate of browning is faster at higher temperatures. Oxygen is taken up by the fruit product during darkening, although darkening may occur in some products under anaerobic conditions. In darkening of dried apricots it was found that damage was greater with larger quantities of oxygen and that oxygen consumption was greater for fruit of 25% moisture than for that of 10%. Temperature is the most important single factor affecting the uptake of oxygen, the rate increasing nearly 4 times for every 10°C rise in temperature.

Sulfur Compounds of Plants

Sulfur compounds are present in the plant in three forms: in the amino acids of proteins, *i.e.,* cystine, methionine, and others; volatile compounds; and sulfates.

It is known that a portion of the protein sulfur is readily split off at boiling or higher temperatures. Peterson (49) found volatile sulfur in clover, beet tops, bluegrass, and milk. This was unexpected, and he suggests that it may come from two sources, from volatile sulfur compounds in the materials used, or from the splitting off of sulfur from the protein and the formation of hydrogen sulfide. He thinks the second the more probable explanation. He found a larger percentage of volatile sulfur compounds in plants grown in a sulfur-rich soil than in those grown in a sulfur-poor soil.

Volatile sulfur compounds. The volatile sulfur compounds are found in plants as glycosides. When treated with acid or with alkali, or when acted upon by enzymes, these glycosides yield a sugar of some closely allied carbohydrate and one or more other substances, frequently phenols, allyl sulfide, or allyl isothiocyanate. The strong flavor of old or stored turnips, rutabagas, and cabbage is probably largely due to sulfur compounds set free by enzymes. When these vegetables are cooked, plant acids are liberated which cause hydrolysis of the volatile sulfur compounds. In addition, H_2S is formed by decomposition of the sulfur compounds by heat. The odor of many of these compounds is familiar, those from onions, garlic, and cooking cabbage being typical examples. Since these sulfur compounds are volatile, foods containing them should be cooked uncovered.

Allyl isothiocyanate is found in mustard seed. The commercial preparation involves maceration of the seed, allowing the enzymes to split the glycoside into the sulfur compound and the sugar residue. The oil is then obtained by distillation with steam. Allyl sulfide (17) is found in the onion family and is prepared commercially from garlic. The strong flavor of onions, leeks, and garlic depends upon the concentration of allyl sulfide.

These volatile compounds escape from the food more rapidly with rise in temperature and breakdown of the plant cells. Hence, the longer onions, leeks, and garlic are cooked, the milder their flavor becomes. Also, because finely minced onion has a greater surface area for volatilization to occur than when cut in large pieces, these substances volatilize more rapidly from finely cut pieces. This is why it is preferable to add onion juice, very finely minced onion, or cooked onion to some foods that are not cooked long or that do not reach a high temperature, such as hamburger or stuffing for fowl or meat. Large pieces of raw onion in a stuffing produce a very strong onion flavor, more concentrated in some areas than others, instead of a subtle, well-blended flavor, for the stuffing never reaches boiling temperature.

The amount of onion and/or garlic added, the fineness of division of the pieces, and the length of cooking all affect the flavor of the finished product to which they are added. The flavor of a food like catsup or chili sauce may be ruined by adding a large quantity of onion or garlic in large pieces near the end of the cooking process. The same amount of onion or garlic added in small pieces, or added in large pieces early in the cooking process, could blend with, instead of dominate, the flavor of the other ingredients.

Sulfur compounds and the cooking of vegetables. It is commonly known that long cooking of such vegetables as cabbage, turnips, cauliflower, and Brussels sprouts develops strong, disagreeable flavors, and that eating of these vegetables may cause discomfort and digestive disturbances. The longer cooking and stronger flavor are accompanied by increased acidity of the vegetables. The length of time of cooking for the strong flavor to develop varies with the vegetable, the temperature of the water when cooking is started, and the proportion of vegetable to water.

Simpson and Halliday (56) have determined the total volatile sulfur and H_2S evolved when cabbage and cauliflower are cooked for different lengths of time. They found that the most acceptable product is obtained when winter cabbage is boiled 7–8 minutes, and spring cabbage 5 minutes. Cauliflower required 8 minutes to become tender. They conclude that with prolonged cooking the decomposition products of sulfur compounds increase and that these products produce the strong taste and odor associated with cabbage and cauliflower. The amount (56) of H_2S increases from the fifth to the twentieth minute of boiling cabbage, and the total volatile sulfur between the seventh and thirtieth minutes. Cauliflower gives off more volatile substances in the same period than cabbage. Masters and Garbutt (44) have found that the amount of sulfide increases up to a certain point and then decreases, becoming fairly constant. Kohman (40) states that in corn the amount of hydrogen sulfide evolved is greater during the first half hour and decreases with each succeeding half hour.

Shilling (55) in determining the amount of H_2S in cooking cabbage, reports that it varies from 1 to 7 mg/300 g of fresh cabbage. The wide variation depends upon the ratio of green to white in the cabbage, the speed of cooking, the length of time of cooking, and the temperature involved in the method, *i.e.*, boiling in water or pressure cooking.

Bigelow (13) has reported that the black spotting in canned corn around the edges of the can is from the formation of H_2S during processing. The amount of sulfide is very small, and there is no objection to it except its appearance. Stevenson (59) states that iron sulfide is formed to a greater extent in canned peas than in canned corn. It is not so noticeable in peas because of their color. It is deposited in scales that break up easily in shipping and handling.

Cellulose

Cellulose forms the structural, fiber, or woody part of the plant. Other substances such as pectic substances may occur in combination with cellulose. In the young plants or the new growth of older plants the cell walls are at first yielding. As they mature, they grow more resistant and may change physically and chemically, their function becoming more specialized with the occurring changes. In tree trunks some cell walls become woody or lignified. Dorée and Barton-Wright (24) state that the stone cells distributed throughout the flesh and particularly near the core of pears are lignified cellulose.

Cellulose is a carbohydrate. It is found in plants in several forms. There is no unanimity of opinion regarding its definition, although the cotton fiber is always taken as a standard cellulose product.

Hemicellulose, wood cellulose, and gelatinized cellulose are names given to different forms of cellulose. Probably each group includes several products. Schorger (54) defines hemicellulose as "a polysaccharide soluble in dilute alkalies and convertible into simple sugars by heating with dilute acids at atmospheric pressure." He adds that a hemicellulose in the natural state should be insoluble in boiling water.

Effect of cooking on structure. The structure of fruits and vegetables consists essentially of cellulose-walled cells cemented together with a mixture of pectic and other substances, forming the middle lamella. The softening in cooking is due to partial solution of the cementing layer and to alteration of the cellulose. Simpson and Halliday (4) have shown that steaming causes the partial breaking up of the wall structure, both cellulose and pectic substances, with an increase of the pectin and pectic acid (or pectates), a decrease of the protopectin and total pectic substances, and an alteration of the cellulose. This last change may be either a process of liberation of cellulose, making it more accessible, or a partial hydrolysis. The changes are progressive with increase in length of time of steaming.

Use of alkalies and acids with vegetables. Ammonia and $NaHCO_3$ added to the water in which vegetables are cooked or ammonia or $(NH_4)_2CO_3$ added to the water in which vegetables are steamed causes the vegetable to soften in a shorter time than if these substances had not been used. The vegetable may become mushy or disintegrate. The disintegration begins with the surface layer of the food, and its depth depends on the length of time of cooking and size of the piece of food.

If vinegar is added to the water in which vegetables are cooked the effect is opposite from that of alkalies; a firmer, more solid texture is obtained, and the vegetable requires longer to cook.

Use of $CaCl_2$. Calcium chloride is used to increase the firmness of foods. Examples are frozen apple slices used principally for pies, canned tomatoes, and various types of pickles. Kertesz (37) states that the calcium combines with pectic acid to form an insoluble calcium pectate gel. This acts as a binding material between the cells and helps to decrease the disintegration of structure caused by heat during processing or cooking. Soaking tomatoes (37) in NaCl softens the structure as the sodium replaces the calcium and magnesium naturally present. The amount of calcium approved by the Food, Drug, and Cosmetic Administration as an optional ingredient in canned tomatoes is 0.07%, or about 6 grains of anhydrous $CaCl_2$ per No. 2 can.

$CaCl_2$ is added either in the last soaking water, when the brine is being removed, or put directly into the sweetened vinegar to crisp cucumber pickles. The proportion has been given as 1 pound of $CaCl_2$ to a barrel of pickles. If the barrel holds 31.5 gallons, this means about 14 grams (0.5 ounce) per gallon.

The flesh and white part of the rind of watermelon, as well as the flesh of muskmelon, citron, and other foods used for sweet pickles or preserves, can be made crisp and firm if soaked in $CaCl_2$. The firmness obtained depends upon the concentration of $CaCl_2$ used and the length of soaking. Soaking 5 to 6 hours usually gives sufficient firmness to prevent shriveling during cooking. The pickle material can be cooked in water until tender, then soaked in the $CaCl_2$ solution, or soaked first and then cooked.

The effect of sugar on the firmness of fruit. The effect of sugar varies somewhat with the amount used in proportion to the quantity of fruit. Osmosis occurs when a sirup has greater sugar concentration than that of the fruit added to it. Osmosis is the transfer of water through a membrane from a region of high concentration to a region of low concentration. The kind of membrane determines whether or not all the dissolved constituents of a solution can pass through the membrane. With a semi-permeable membrane only the water passes. As the permeability of the membrane increases, larger and larger ions or molecules may pass through it.

The skin and cell walls of fruit serve as membrane; their permeability to sugar varies. Cooking seems in most instances to increase the permeability. Of course, many changes other than increase in the permeability to sugar occur when the fruit is cooked.

When cooked in a sirup some fruits tend to keep their shape, some become mushy, some shrivel, and others tend to collapse or flatten out. In general, fruits tend to stay whole better if cooked in a sirup. For purées the fruit is cooked in water and the sugar added later. Some apples, some plums, and most berries can be cooked directly in sirup without noticeable toughening of the fruit. Peaches, apricots, most apples, and most plums absorb sugar satisfactorily. On the other hand, a fruit like Keifer pears is dehydrated if cooked directly in a sirup, and becomes shriveled, hard, and rubbery. It is necessary to soften the fruit and increase its permeability by cooking before the sugar is added. Later work has shown that fruit like Keifer pears and quinces can be cooked by adding the sugar directly to them without preliminary cooking, but that it is necessary to start with an excess of thin sirup and cook slowly to evaporate the excess of liquid. However, so long a time is required that the method is not practical.

To prevent fruit like strawberries from floating to the top of the finished preserve, the sugar can be added to the berries and stored in the refrigerator overnight. The fruit loses water and some of its interior gas, shrinks somewhat, becomes slightly tougher, and some sugar penetrates the berries. If heated slowly before boiling commences, there is time for the sugar to penetrate the fruit. The fruit is plump and does not have as much tendency to float, when put in the container. In the commercially vacuum-processed berries, floating in the can is prevented by adding the berries, to which part of the sugar has previously been added, to a hot sirup, but further heating is not continued until the berries have stood for a few minutes. By producing a vacuum, the greater pressure within the berry tends to puff it up; by breaking the vacuum, flattening occurs. In this way the process of osmosis is helped.

Strawberries, cherries, and some other fruits develop a strong flavor when they are cooked too long. To cook in as short a time as possible, sugar instead of sirup can be added to the fruit. Sirup increases the amount of water to be evaporated. Cooking can be rapid, and a large proportion of sugar to berries can be used. For home use 1.5 pounds of sugar to each pound of strawberries requires only a short cooking period for the preserves to reach a temperature of 103°C, which gives a concentration of 60% of sugar. See Table 11.

The popularity of sun preserves for certain fruits is due to osmosis being slow and complete. If the fruit is heated, the heating period is short, so that strong flavors are not developed, less sugar is caramelized, and the aromatic substances are not lost to such an extent as in long cooking.

Potatoes

Cooking quality of potatoes. Surveys of consumer preference have shown that mealiness and whiteness of the cooked product are the two most important cooking characteristics of potatoes, since the flavor is readily altered by addition of various substances at the time of cooking. Potatoes giving a white, mealy product are best for baking and boiling. The amount of sloughing during boiling is also important. For deep-fat frying, slicing for salad, and similar uses, a firm, waxy texture is preferred. Many investigators (64, 71, 72, 75, 83) have studied the factors affecting the cooking quality of potatoes.

Effect of cooking. Cooking (74) causes mechanical disintegration of the tuber by cell separation, leaving the cells themselves intact. This is accompanied by partial gelatinization of the starch, degradation of the pectins, coagulation of the proteins, and an increase in the digestibility of the cellulose. Baking and frying caramelize some of the sugar present. Two fundamental changes (77) are necessary to convert raw potato into cooked potato: (*a*) gelatinization of the starch, and (*b*) a marked decrease in the cell adhesion of the tissue.

Mealiness. Investigators have tried to connect some physical characteristic of the potato with its mealiness after cooking. The specific gravity of the potato has been reported as giving an index to mealiness (67, 73). However, Greenwood et al. (69) have shown that a close correlation between specific gravity and mealiness after cooking is found in potatoes grown under some conditions, whereas there is no correlation for these two properties for the same variety of potatoes grown under other conditions. Mealiness of the potato is increased by loss of water during cooking, but a waxy potato cannot be converted into a mealy one by this method (68).

Sloughing. The breaking up of the outer layers of the potato tuber during boiling is known as sloughing. Barmore (63) states that storage at 18.3°C (65°F) decreases the tendency to slough. This decrease is related to loss of water during storage, indicating that rigidity of the tuber is at least partly responsible for sloughing. Another factor in sloughing is the calcium content of the tuber. Pyke and Johnson (78) report that "sloughing can be controlled by the presence of enough calcium salt in the cooking medium to maintain or raise slightly the calcium content of the potato. Ordinarily, the calcium content of the tuber decreases rapidly with cooking, especially in salted water." The addition of calcium salts to the cooking medium would counteract this decrease.

Discoloration of potatoes and potato products. Discoloration of potatoes is of three types: (*a*) darkening of the cut surface of raw potatoes, (*b*) a gradual darkening of the cooked potato upon exposure to air, and (*c*) darkening caused by the browning reaction.

The darkening of cut surfaces of raw potatoes is probably enzyme activated. Wallerstein et al. (85) in a series of articles indicate the phenolase enzyme tyrosinase is mainly responsible for this darkening. These investigators also give quantitative methods for the determination of potato peroxidase activity. This darkening is inhibited by cooking.

The second type of discoloration, that in the cooked potato is more serious, as it results in an unattractive looking product (66, 81, 84). Various workers report that tubers that blacken contain a larger amount of tyrosine than those that remain white. Robinson (79) states that the black discoloration cannot be melanin as the color disappears rapidly in acid solution at *p*H 3.0, whereas melanin is stable at this *p*H. She believes that the pigment is an iron compound. Bowman and Hanning (65) have shown that the discoloration is more intense if the potatoes are steamed or boiled before peeling. They found the discoloration could be prevented by adding acid during cooking and that the discoloration was reversible with variation in hydrogen-ion concentration for the various acids used with the exception of boric and benzoic acids. Color scores of potatoes that normally cooked dark were significantly higher when cream of tartar was added. The undesirable hardening effect of the acid salt was less noticeable if the cream of tartar was added at the mid-point of cooking.

The literature on the deterioration of dehydrated potatoes, with flavor and color changes associated with the browning reaction, have been reviewed by Ross (82). In baked potatoes the browning of the cut surfaces and areas beneath the skin may enhance the flavor. In potato chips the light brown color is desirable, but a dark or nearly black color is accompanied with a disagreeable flavor.

Storage. The storage temperature (86) affects the quality of the cooked potatoes. In general, potatoes from storage at 4.4°C (40°F) were considered fair in quality when cooked; those from 0° to 2.2°C (32° to 36°F) were poor; those from 10° to 21.1°C (50° to 70°F) good; and those from 15.5°C (60°F) very good. The palatability (70) decreases with increasing length of storage.

Potato chips. The sugar content (80) of the potato is the chemical factor most obviously related to the quality of the potato chips and to the frying temperature to be used. With a high sugar content the chips become too brown, with production of a disagreeable astringent flavor, due to caramelization of sugar, before they are sufficiently cooked. The concentration of sugar increases in potatoes stored at low temperature. At ordinary temperatures the sugar is used up in respiration; at lower temperatures metabolism is retarded but sugar production by enzymes proceeds, so that sugar accumulates.

Peacock and Brunstetter (76) have reported a very simple test for determining the cooking value of potatoes by accumulated sugars. One cubic centimeter of a saturated aqueous solution of picric acid and 1 cubic centimeter of a 20% sodium carbonate solution are placed in a test tube. To this is added a piece of potato of definite length cut with a cork borer. The solution is heated carefully to prevent boiling over for 1 minute. If the solution does not become much darker it indicates that the potato has little sugar and is suitable for both chips and "French fries." With increasing sugar content the solution becomes darker and darker when time of heating and size of piece of potato are kept standardized. The darkest shade given by Peacock and Brunstetter is a dark garnet-brown; but Swalley tested some potatoes that gave shades 2 degrees darker in color than dark garnet-brown, the darkest being nearly black. Potato slices fried for a definite ime in fat at a definite temperature become browner and browner as the ugar content increases and give perfect correlations with the picric acid est. In general Swalley found that, the longer the potatoes were stored at 0°C (32°F), the longer the time required for storage at room temperaure (those stored at 0°C for 31 days required 45 days at room temperaure) before good chips were obtained.

Wright et al. (86) found that potatoes stored at 0–2.2°C (32–36°F) were not suitable for French fries, as they browned too quickly and had a burned flavor. To some extent this was also true of potatoes stored at 4.4°C (40°F). As the storage temperature increased, the time necessary for cooking increased. Potatoes stored at 15.5–21.1°C (60–70°F) gave fries of attractive golden-brown color, mealy texture, and good flavor. Similar results were obtained with chips.

Preparation of chips. Because it is difficult or impossible to slice the potatoes evenly by hand, they should be cut with a slicer. If salt is added to the soaking water the slices are partially dehydrated during the soaking; thus a shorter time is required for cooking and no addition of salt is necessary after cooking. For ¼ pound of potato and ½ cup of water about 8 grams of salt are required.

Cooking chips. The cooking time and temperature are dependent to a certain extent on the quantity of potatoes added to a given amount of fat, as well as on the sugar content of the potato. For ¼ pound of slices about 3 minutes are required when the initial temperature of the fat is 190°C and the quantity of fat about 2 to 2.5 pounds. Smaller quantities of potatoes cook in a shorter time. With higher sugar content, lower temperatures should be used. The chips are done when bubbling of the fat ceases, indicating that the major portion of the water has evaporated.

Cooking Dry Legumes

The dried legumes commonly used for food include navy, lima, kidney, soy, and other varieties of beans, lentils, and dried peas. In cooking, the moisture lost during drying is replaced by absorption, and the legume is softened. This requires a longer cooking period than for fresh legumes, so that methods of cooking that shorten the cooking process are more important for dried legumes than for fresh vegetables.

Hard water. The hardness of the cooking water is one of the most important factors to consider in cooking dry legumes (87, 88, 89, 90, 91). Hence it seems desirable to define hard water. Hard water contains the salts of calcium, magnesium, and sometimes iron. Hardness of water may be temporary or permanent. Water containing calcium and magnesium hydrogen carbonates is termed temporary hard water since heating decomposes these salts, forming carbonates which deposit as crusts on the inside of the cooking utensil. Such waters become less hard when boiled. Permanent hard water contains the sulfates of magnesium and calcium which cannot be removed by boiling. Some water is both temporarily and permanently hard.

Softened water, which is used a great deal at the present time, has the calcium and magnesium replaced by sodium. The author has noticed, since softened water is used in the Home Economics building at Iowa State College, that fresh green peas never become hard as they sometimes had with the old permanently hard water. Also, the difference between the time required for cooking soaked and unsoaked dried beans is very much shorter.

Effect of mineral content of the water upon cooking of dry legumes. Huenink and Bartow (88), trying to determine why the canned products from some factories were always superior in quality to those of others, found that the mineral content of the water affected the softening of dried beans during cooking. They found that beans canned in a sirup and distilled water were very tender and would grade strictly fancy on the market. When they added $CaCl_2$, the hardness of the processed beans increased with increasing amounts of $CaCl_2$, the ones with 1000 ppm being nearly as hard as uncooked beans. The series with 100 to 200 parts of $CaCl_2$ per million of water were hard and tough, would grade standard on the market, and would be called underprocessed. Continuing their work, they tried the following salts: $CaCl_2$, $CaSO_4$, $Ca(HCO_3)_2$, $MgSO_4$, $Mg(HCO_3)_2$, Na_2CO_3, and $NaHCO_3$. They found that the calcium and magnesium salts hardened the beans whether as chlorides, sulfates, or carbonates. The calcium and magnesium hydrogen carbonates had a less consistent hardening effect than the other salts. Both Na_2CO_3 and $NaHCO_3$ had a softening effect; with larger quantities the beans appeared overcooked.

Van der Marel (91) investigated the effect of various salts, bases, and acids on softening during cooking of dry peas. The results for "good" and "difficult" cooking varieties are given in Table 14.

TABLE 14

Cooking Dry Peas (*Van der Marel*)

Type of water and substance added	Peas remaining hard after cooking 1.5 hr. Good cooking type %	Peas remaining hard after soaking 24 hr and boiling 2 hr. Difficult cooking type %
Distilled water	5	43
Amsterdam city water	14	67
Formic acid, 0.01 *M*	68	..
$CaCl_2$, 0.01 *M*	100	..
$NaHCO_3$, 0.01 *M*	2	4
NH_4OH, 0.01 *M*	..	0

The pectic substances of bean coats. Van der Marel concluded that anything that made the pectic substances of the legume coat more soluble had a softening effect in cooking. Snyder (90) noticed that, if the seed coat of pea or Great Northern beans was injured or scarified, that the beans swelled readily during cooking and cooked in a shorter time. The entrance of water into the beans was not uniform over the entire surface of the bean, most of the water entering through the micropyle and germinal area.

Effect of soaking. Legumes have to absorb water and increase their weight before the effect of the soaking brings about shortening of the cooking time. Lima beans need to nearly double their weight. The temperature of the water also affects the time required for soaking. When boiling water was poured over lima beans swelling occurred in 4–5 hours as compared to doubling their weight in 7–8 hours when room-temperature water was used. Soaking a given variety of soybeans in softened water at room temperature overnight halved the cooking time. A still shorter cooking time was brought about by pouring boiling water over the soybeans and soaking 3–4 hours. When pea or Great Northern beans were soaked in water at 49°C the maximum amount of water was absorbed in 6 hours (90). Class results have indicated that soaked beans are lighter in color and less strong in flavor than the unsoaked ones.

The use of $NaHCO_3$ with legumes. The use of soda has shortened the cooking time of legumes in various studies (87, 88, 89, 90, 91). The amount of soda to use varies with the hardness of the water, and possibly with the legume. Snyder (90) found ⅛ teaspoon soda per pint of water was sufficient to shorten the cooking time, except with one very hard water. Greenwood (87) using pinto beans found the shortest cooking time was obtained when the beans were soaked in a 0.5% soda solution (1.5 teaspoons $NaHCO_3$ to 5 cups of water).

The soda may be added to the cooking or the soaking water. The latter is the preferable method. When the soda has been added to the cooking water in class work, the beans become mushy on the outside while the center is still hard.

Variation in legumes. A given variety of legume has been found to vary in the time required for cooking over different seasons. Variation also occurs among varieties. Some varieties of soybeans are nearly impossible to cook, even in a pressure cooker. Varieties easier to cook are used for edible purposes.

Other factors. Snyder (90) found that molasses and tomato juice had an effect similar to acid on the cooking time, but could be added without injurious effect after the beans were cooked. Beans that cooked rapidly over a burner also baked satisfactorily. In class results, it was found that all varieties of beans cooked in a shorter time in a covered than in an uncovered vessel. This may be due to the cooling effect of evaporation of the water at the surface. Greenwood (87) found that boiling the water

20–30 minutes to precipitate the calcium and magnesium salts before using for cooking the beans was beneficial. Also in using hard water better results were obtained by boiling gently to keep evaporation of the water to a minimum, thus avoiding the necessity of adding more water and increasing the total salts added.

Losses in cooking legumes. Masters (89) was interested in the total solids lost during cooking of legumes. The loss of solids during the cooking of butter beans was about 10.5–11% for unsoaked beans, and about 12.5% for soaked ones. The greatest loss occurred when a 0.25% $NaHCO_3$ was used for cooking. Larger amounts of soda caused greater losses, owing to disintegration of the beans. Soaking but not cooking in a 1% soda solution decreased the loss of the total solids. Discarding the soaking water gave no greater loss than when the beans were cooked in the water in which they were soaked.

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Cooking dry legumes

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FRUITS AND VEGETABLES

Experiment 8.

A. To determine the time required to cook a vegetable to produce a good color, texture, and flavor.

Use fresh or frozen vegetables, or compare both fresh and frozen. The home-size frozen vegetable packs weigh 10, 12, or 14 ounces, depending on the vegetable selected. Use a fourth or a half of each package as desired. Use the same quantity of the prepared fresh vegetable. Use peas, carrots, green beans, sweet corn, lima beans, broccoli, cabbage, celery, onions, Brussels sprouts, or other vegetables common to your community. Observe the color of the cooked vegetable, its texture, and its flavor. Even with many mild-flavored vegetables, cooking 1–2 minutes too long or too little often makes the difference between a desirable and an undesirable product. Depending on time required for cooking the vegetable, increase or decrease the cooking time, *i.e.*, longer intervals for a vegetable requiring a longer time to cook and shorter intervals for a vegetable requiring a shorter time to cook. Note effect of under- and overcooking on color, texture, and flavor.

1. Use an open kettle. Have the water boiling when the vegetable is added. Keep it boiling rapidly. Add boiling water if necessary. Rapid boiling requires more fuel, but the steam above the vegetable prevents oxygen coming in contact with the vegetables, particularly when the quantity of water used is small. If water is left, it should be saved to observe its color and flavor.
2. Repeat A1, but cook longer than to give a desirable product.
3. Repeat A1, but cook less time than gives a desirable product.

If desired, repeat A with a waterless cooker (using no water), a pressure saucepan (follow directions of manufacturer), and a steamer, but regulate the cooking time for each utensil accordingly.

B. To determine the amount of water left at the end of the cooking period that results in a product of best color, texture, and flavor.

Use the cooking time found best in A. Use a mild, a strong, a green, a yellow, a red, and a white vegetable. Save the water. Note particularly the sweetness and other flavors of the water and vegetables.

1. Use an open kettle. Have the water boiling when the vegetable is added, and boil rapidly during cooking. The amount of water used should be such that none or 1–3 teaspoons will be left at the end of the cooking period.
2. Repeat B1, with about ¼ cup of water left.
3. Repeat B1, with about ½ cup of water left.
4. Repeat B1, with about 1 cup of water left.
5. Repeat B1, but scald or blanch the vegetable, *i.e.*, after cooking 2 minutes discard the water and replace with a similar amount of fresh boiling water. Continue cooking until done.

C. To compare vegetables cooked by different methods. Use a variety of vegetables. Some vegetables may be palatable cooked by any method, some may be more desirable by a given method. Use time of cooking and amount of water found best under A and B.

1. Use an open kettle.
2. Use a pressure saucepan.
3. Use a waterless cooker.
4. Use a steamer.
5. Cook a strong-flavored vegetable in a distilling flask. Use 1 pint or sufficient water so that the flask will not boil dry.

Catch the distillate in a flask held in ice water. Catch the distillate in 4 portions, changing the flask every 3 minutes. Do not count the time for the first distillate caught in the flask until the water in the distilling flask is boilng. Cork the flasks containing the distillate until the class is ready to taste nd smell the distillate. Which is stronger, the first liquid that distils over or he last portion? Are any of the flavoring and aromatic substances of cabbage, urnips, and onions volatile?

Some of the distillate may be tested for sulfides by adding a few drops of ead acetate. Test the distillate with litmus.

Taste the cooking water and vegetable. In which case is the flavor of the egetable best? Is blanching desirable? Do these experiments suggest any eason why the juice of most canned vegetables is stronger than that from he fresh vegetables? If you do not want to discard the water in which a trong-flavored vegetable is cooked, how would you cook the vegetable? How use the water? Test some of the cooking waters for sugar.

Experiment 9.

A. To determine the effect of using water of various acidities and using milk upon color, texture, and flavor of a green vegetable.

The amount of water to give a green, not an olive-green colored vegetable, vill vary. For example, Ames water has about 350 ppm of hardness. This vater would have more alkaline salts to neutralize plant acids than a water vith 50 parts of hardness. From the standpoint of color, use the amount of ap water found to give the best green color under Experiment 8B. Use this ame amount for the other part of the experiment.

1. Use tap water.
2. Use distilled water.
3. Use distilled water plus ⅛ teaspoon soda.
4. Use distilled water plus 1, 2, or 3 teaspoons vinegar.
5. Use milk.

B. Repeat A with an orange or yellow vegetable.

C. Repeat A with a red vegetable other than beets or tomatoes.

D. Repeat A with a white vegetable like cauliflower.

E. Use a strong-flavored vegetable like cabbage, and compare particularly the flavor when the vegetable is cooked in milk with that of portions of the same vegetable cooked in the various waters.

What is the effect of long cooking on strong-flavored vegetables? Are some vegetables often overcooked? Is cabbage sometimes cooked longer than 25 to 30 minutes? Name several strong-flavored vegetables. Do cabbage and cauliflower turn a brownish red unless cooked too long? Do onions become stronger in flavor with longer cooking? What length of time of cooking produces the best-flavored product for onions, cauliflower, and the other vegetables used? With which vegetables would you have considerable water left at the end of the cooking period? Would the age of the vegetable, that is, young or old carrots, turnips, etc., make any difference in the quantity of water that is desirable to be left at the end of the cooking period? With which would you evaporate the water? Would you increase the water proportionately for a larger quantity of vegetable? Do vegetables like cabbage and onions lose juice during cooking that adds to the cooking liquid? What is the percentage of water found in some common vegetables?

Is the flavor of the vegetables cooked in milk as strong as when cooked in water? Do any of the vegetables curdle the milk? Which ones? (See chapter on milk.)

What is the effect on the color of white vegetables of cooking in alkaline water? In distilled water?

Experiment 10.

To determine the effect of alkaline and neutral water upon the color of white cereals.

1*a*. To 1⅓ cups of boiling water add ¼ cup of washed rice. Cook until tender. Add more boiling water if necessary during cooking. Remove about ½ of the cooked rice from the sauce pan and drain.

1*b*. To the rice remaining in the sauce pan from 1*a*, add ⅛ to 1/16 teaspoon of cream of tartar. Cook 2 minutes and drain.

2*a*. To 1⅓ cups of boiling distilled water, add ¼ cup of rice washed in distilled water. Add boiling distilled water during cooking if necessary. When the rice is tender, remove about ½ of the cooked rice from the saucepan and drain.

2*b*. To the rice remaining in the saucepan from 2*a*, add ⅛ to 1/16 teaspoon of soda. Cook 2 minutes, then drain.

Experiment 11.

To determine the best method of cooking dry legumes.

Use 50 grams of dried beans for each experiment. Keep a record of the time required for cooking, the weight after soaking, and the weight after cooking. Start the soaked beans to cook in 1 cup of boiling water and the unsoaked beans in 1 pint. If the beans become dry before they are cooked, add boiling water of the same kind used in that particular experiment. Cook all the beans in covered pans. Test the beans with the sharp point of a knife or fork. Compare with your neighbors' results, to try to have all cooked to the same stage of doneness. If you have water softener, to soften hard water, repeat the experiments that call for tap water to compare with the results for hard water and distilled water.

1. Wash the beans, and soak overnight in tap water. Discard the water in which the beans were soaked. Weigh the beans. Add fresh tap water and cook until tender. Drain and weigh.

2. Soak overnight in tap water to which ⅛ teaspoon of soda is added. Discard the soaking water and proceed as in 1.

3. Soak the beans overnight in distilled water. Discard the soaking water, and weigh the beans. Add fresh distilled water, and cook until tender. Drain and weigh the beans.

4. Soak overnight in distilled water to which ⅛ teaspoon of soda is added. Discard the soaking water, and weigh the beans. Proceed as in 3.

5. Cook in tap water without soaking. Weigh.

6. Cook in tap water to which ⅛ teaspoon of soda is added. Cook for 10 minutes, then discard the water and add fresh water. Cook until tender. Weigh.

7. Cook in distilled water until tender. Weigh.

8. Cook in tap water to which ¼ teaspoon salt per 50 grams of beans has been added. Weigh.

9. Cook in the pressure cooker for 30 minutes at 20 pounds pressure.

10. Cook in distilled water to which 1 tablespoon of vinegar is added.

11. Pour boiling water on the beans. Let stand. Weigh beans every hour o compare the length of time required for soaking in warm and cold water.

Compare the time required for cooking by the different methods. In which s the best product obtained? Do any of the beans tend to lose their shape? Which beans cook in the shortest time? What is the effect of soaking on the olor and flavor of the beans? On the time required for cooking?

CHAPTER

6

Pectic Substances, Jelly, Jam

THE PECTIC SUBSTANCES

The pectic substances are carbohydrate derivatives. They occur in practically all plant tissue and particularly in the middle lamella of the cell wall. Pectins are used in jelly and jam. Some other uses of pectin are mentioned. The Research and Development Associates, Food and Container Institute, are interested in the pectic substances in relation to hydration of vegetables for the Armed Forces.

Nomenclature. The revised nomenclature of the pectic substances was adopted by the American Chemical Society in 1944. Full definitions and statements regarding the nomenclature are given (26, 27). The following are abstracts of the definitions used by Baker (5):

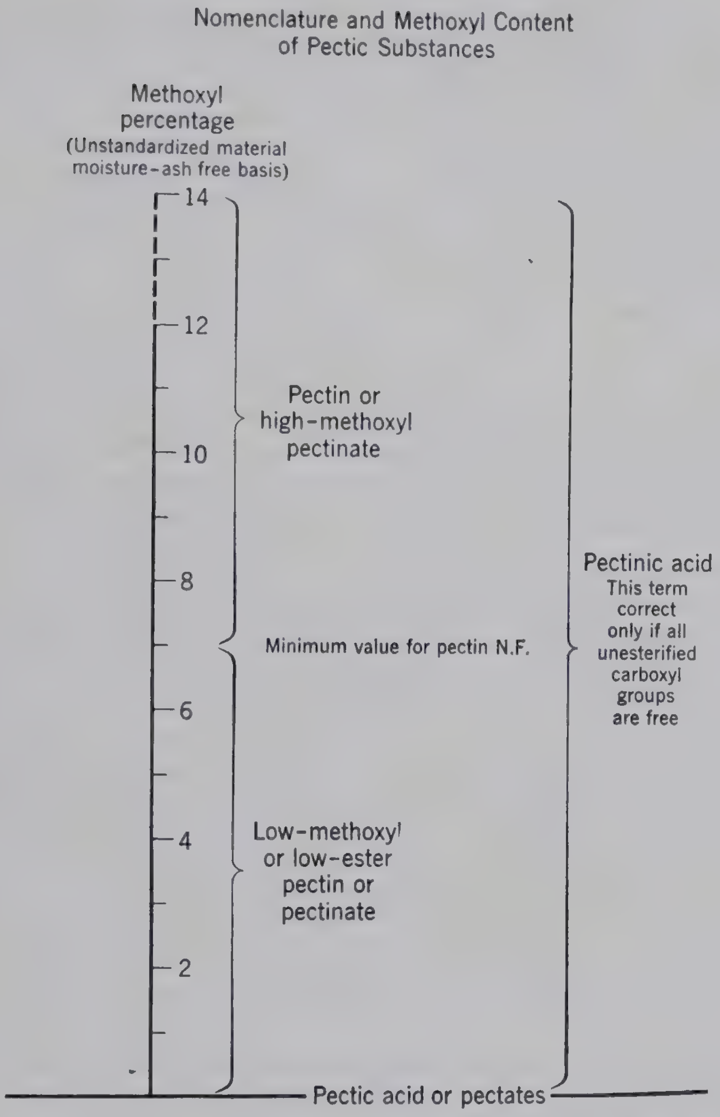
Pectic substances, the group designation.
Protopectin, water-insoluble parent substances.
Pectinic acids, colloidal polygalacturonic acids with more than a negligible proportion of methyl-ester groups.
Pectinates, normal or acid salts of pectinic acids.
Pectin, general term for pectinic acids or pectinates capable of forming gels with sugar and acid.
Pectic acid, colloidal polygalacturonic acids mostly free of methyl-ester groups.
Pectates, normal or acid salts of pectic acids.

The relation between pectins, pectinic acids, pectic acids, and pectates as well as the difference between high- and low-methoxyl pectins is better shown in the chart developed by Joseph (24) than by descriptions. See Fig. 16*a*.

The pectic enzymes. The following concerning the pectic enzymes is taken from Kertesz's book, *The Pectic Substances.*

Protopectinase is the enzyme which hydrolyzes or dissolves pectin, resulting in separation of the plant cells. It has not been isolated.

Pectin-polygalacturonase (pectinase, pectolase) hydrolyzes the 1,4-glucosidic linkages in the polygalacturonic acid chain, thus reducing the size of the pectin molecule and eventually giving only galacturonic acid units.


Nomenclature and Methoxyl Content of Pectic Substances
Methoxyl percentage
(Unstandardized material moisture-ash free basis)
14
12
10
8
6
4
2
Pectin or high-methoxyl pectinate
Minimum value for pectin N.F.
Low-methoxyl or low-ester pectin or pectinate
Pectinic acid
This term correct only if all unesterified carboxyl groups are free
Pectic acid or pectates

Courtesy Dr. Joseph and Sunkist Growers

FIG. 16*a*. Diagram showing the relation between pectins (high- and low-methoxyl), pectinic acid, pectic acid, and pectates.

It is produced by microorganisms and may or may not be present in fruit.

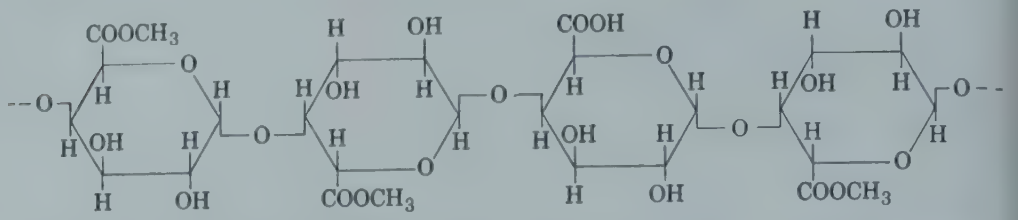
Pectin acid "depolymerase" acts on pectic acid, having little effect upon pectinic acids. Its optimum action is around *p*H 4.5, and it is activated by NaCl.

Pectin-methylesterase (pectase) catalyzes the hydrolysis of the methyl ester groups of pectinic acids.

Composition and Structure

The pectin molecule is a polymer of galacturonic acid units linked together in a chain-like structure through carbons 1 and 4. The side chains are methoxyl groups, $-COOCH_3$, or the corresponding acid, $-COOH$.

One end of the pectin molecule has a reducing group, the other end a nonreducing group. The following is a portion of the pectin chain.



The pectin molecules are elongated in shape. This property is responsible for their forming viscous sols. The polymer chains may be linear, and these may be further combined into aggregates through ester, lactone, or anhydride bridges between chains (26). A branched molecule like amylopectin is a possibility, or the elongated chain may be folded. Other possible structures are discussed in the literature. Since the pectic substances are in various stages of polymerization, it follows that these substances are heterogeneous. In addition to the pectic substances varying in chain length, they also undergo changes during certain periods of growth and decrease in size with maturity and as the fruit becomes overripe. Hence, it is not surprising that the reported number of units of galacturonic acids in a chain of a pectic substance, and hence the molecular weight, varies over a wide range. Kaufman et al. (25) state that a high grade of pectin may have a molecular weight of 200,000 with more than 1000 galacturonic acid units in each molecule. Joseph and Havighorst (23) state that the molecular weight of pectin may be 200,000–300,000.

Not only does the pectin molecule vary in size, but the degree of esterification may vary, and these methoxyl groups may be distributed in a regular or an irregular manner.

Arabans and galactans (26) are found in the plant tissues. They may be extracted with the pectic substances and for many years were thought to be a part of the pectin molecule. Myers and Baker (35) report the following constituents from lemon albedo: galacturonic acid 87–95.2%, arabinose 3–7.7%, galactose 0.05–6.4%, and acetic acid 1.9–4.7%. Kertesz (26) reports that both formic and acetic acids are formed from glucose and galacturonic acid when heated with alkali in the manner used by Myers and Baker. He concludes that acetyl groups are not likely to occur in juices from fruits, but are found in pectins from beets, regardless of the extent of purification.

Characteristics and Uses of Pectic Substances

The outstanding characteristic of pectin is its ability to form gels. Other utilizable characteristics of the pectins for definition purposes are their (*a*) insolubility in alcohol and acetone and (*b*) the ease with which they are deesterfied by alkalies at ordinary temperatures to give pectic acid. Pectic substances have many other properties, such as their viscosity in sols, reducing power, and optical properties. The ability to reduce iodine in alkaline solution in the cold is used in estimating the chain length of the pectin molecule. The viscosity of pectin sols is used to estimate the amount of sugar necessary to make fruit jellies.

High-methoxyl pectins. Only the pectins with a high methoxyl content (Fig. 16*a*) are suitable for making fruit juice jellies by heating with sugar at a suitable hydrogen-ion concentration. Some other uses for high-methoxyl pectins (22) are confectionery pieces, emulsions, glazes, and malted milk thickeners.

Low-methoxyl pectins. Low-methoxyl pectins are characterized by low percentages of methoxyl groups, Fig. 16*a*. In contrast to high-methoxyl pectins, they form gels with little or no sugar, provided calcium or other polyvalent ions are present to link the pectin molecules together to form the gel. Kaufman et al. (25) state that the major difference in using magnesium and calcium salts is that magnesium gives gels that melt at low temperatures. Low-methoxyl gels like tomato aspic (22) start to set around 77°C and are of servable consistency at temperatures as high as 47–49°C.

Another advantage of the low-methoxyl pectins is that the gels can be formed over a wide *p*H range from about 2.5 to 6.5 (26). Pectin can be used to form milk gels around *p*H 6.5 (22). The calcium requirement varies with the *p*H of the sol. A tomato aspic may require 1.5 ounces of $CaCl_2$ per pound of pectin at *p*H 3.6 and about 2 ounces at *p*H 3.8–3.9. Joseph (22) states that low-methoxyl-content gels require about 0.7–1.5% pectin. Vegetable and fruit juices have about half the calcium needed for good gels, whereas milk has all the calcium needed for milk gel puddings.

The strength of low-methoxyl-content gels is largely dependent on the size of the pectin molecule and only slightly on the degree of esterification (26).

Joseph (22) gives the following uses for low-methoxyl pectins: tomato aspic gels, canned fruit salad and vegetable gels, consomme and low-sugar diabetic gels, milk pudding gels, and frozen strawberries. For still other uses, see Chapter 27 in *The Pectic Substances* (26).

Fast- and slow-setting pectins. Joseph and Havighorst (23) state that the pectin molecule can be "shortened or made more thread-like." This alteration produces the rapid- and slow-setting pectins made for special purposes. A fast-setting pectin may be used in jams to prevent the fruit pulp from floating to the top of the container, whereas a slow-setting pectin is used in starch cast confectionery gels. Joseph (22) gives a convenient table with type of pectin, typical use, approximate amount of pectin needed in the final product, and important factors concerning the product or use of the pectin.

Variations in pectins. It is well known that pectin from different sources has different characteristics. This is attributed to (*a*) differences in molecular size of the pectin, (*b*) the degree of esterification of the galacturonic acid units, and (*c*) the amount of accompanying "ballast" material such as pentosans. It is also possible that the structure of the pectin molecule as well as the manner of esterification, *i.e.,* regular or irregular, may affect the pectin characteristics.

Jellies from different types of pectins. Olsen (36) states that jellies made from citrus pectins are comparatively friable and have little elasticity, whereas jellies made from apple pectins are highly elastic but require and tolerate less acid than citrus-pectin jellies similarly prepared. Cranberry pectin tends to yield firm jellies which will not spread readily. Cox (10) states that better-texture cranberry jelly for spreading purposes is obtained if the pectin occurring in the juice is hydrolyzed by adding the enzyme pectinase, available commercially under the name Pectinol. The juice is then heated to inactivate the enzyme, and a slower-setting pectin is added to the juice. With a rapid-setting pectin gelation may start before the sirup is poured, and the breakage during pouring produces small lumps in the jelly.

Pectic acid. Pectic acid is the demethylated pectin. It is rendered insoluble by calcium salts and precipitated. Determination of the amount of calcium pectate (9) has been used to quantitatively estimate the pectin. Baker (5) states that gels can be made from nearly demethylated pectin if the precipitation by polyvalent ions is retarded. This can be done by the use of polyphosphates.

Commercial Pectins

Kertesz (26) gives the historical development of commercial pectin, as well as pectin production, and the manufacturing process. Early commercial pectin was extracted from apple pomace and was sold principally in the liquid form. Pectin is still made from apple pomace, but the bulk of the commercial pectin is now obtained from citrus albedo, a waste product after making citrus juices.

Pectin grade and jelly units. The grade of pectin is determined by the amount of sugar which can be used with 1 pound of pectin to yield a 65%-soluble-solids jelly of standard strength at 26°C under optimum conditions of gelation (5). In general the greater the amount of sugar which can be used, the larger is the yield of jelly. Pectins are sold on the basis of grade.

The term jelly units (5) is defined as the product of the yield of pectin times its grade. The grade of the pectin is closely related to the average length of the pectin molecule. The longer the pectin chains, the higher is the pectin grade.

Extraction of commercial pectin. The commercial value of a material from which the pectic substances are extracted is related to the number of jelly units it yields. Extraction is made with acidified water. The fruit acids, citric, malic, and tartaric as well as lactic and acetic acid, have been used. Phosphoric acid has been widely used. Kertesz (26) states that there is an increasing tendency in the last decade to use the cheaper mineral acids, hydrochloric and sulfuric, particularly if the pectin is to be precipitated from the extract. The efficiency of extraction is dependent upon (*a*) the time of heating, (*b*) the extraction temperature, and (*c*) the *p*H. With 3 dependent variables there are different combinations of the above conditions that produce efficient extraction. For example, using citrus albedo at boiling temperatures for 30 minutes, Myers and Baker (33) obtained the highest pectin grade at *p*H 2.40. The greatest number of jelly units was obtained at *p*H 2.15 by boiling 30 minutes. They also found that the pectin yield varied with the acid used: with tartaric acid the greater yield was at *p*H 2.0; with hydrochloric acid, at *p*H 1.45.

When the extraction temperature was varied from 40°C to boiling Myers and Baker (34) found that the jelly grade of the pectin decreased as the extraction temperature was elevated, provided the extraction time was kept constant. The reduction in jelly grade was slight between 40° and 70°C but increased rapidly between 70° and 100°. At temperatures below 60°C with extraction time constant at 30 minutes, practically no pectin was obtained unless the *p*H was 3 or lower.

With 30 minutes' extraction time the optimum jelly units were extracted at 78°C (34). When the extraction time was increased to 1 hour, the optimum jelly units were obtained at 70° at *p*H 1.45. Hinton (19) also found less loss in jellying power if the pectin was extracted at 80° than at 100°C.

To summarize, the following generalizations may be made: with *p*H and extraction temperature kept constant there is an optimum time for extraction of the pectin. With longer than the optimum time the pectin is degraded, the degradation being faster at higher temperatures; with a shorter time too little pectin is extracted. With extraction temperature and time kept constant there is an optimum *p*H at which the most jelly units are extracted; with too great a hydrogen-ion concentration too large a proportion of the pectin is demethylated (19); with too low a hydrogen-ion concentration the pectin is degraded. With extraction time and *p*H kept constant there is an optimum temperature for extraction of the pectin. Extraction is very slow at low temperatures, more rapid at higher temperatures, but degradation is also more rapid at higher temperatures.

Types of commercial pectins. Commercial pectin is marketed in two forms: (*a*) the liquid and (*b*) the powdered dry. Both types have advantages and disadvantages.

Rooker (39) states that the powdered will eventually replace the liquid pectins. Since the liquid type contains 3–5% pectin (26) the bulk and weight to be shipped is large. The powder (39) "is cheaper, easier to handle, haul, cart, and store. It does not spoil and deteriorate. Powdered apple pectin retains its jellying strength indefinitely while sirup pectins deteriorate if kept any material length of time. A container of powdered pectin may be opened and used as needed, while a container of pectin sirup must be used almost at once or the balance of the opened can will spoil."

Since molds produce enzymes that degrade pectin rapidly, it is important to prevent mold growth in opened liquid pectin.

The disadvantage of the powdered pectin is its tendency to lump when added to fruit juice. The pectin particles may be treated to keep them from lumping. This may be accomplished by separating the pectin particles with sugar.

Fruits and Fruit Juices

Constituents of fruits. Fruits (30) are composed mainly of water, 78–88%. The distinctive aroma comes from small amounts of volatile essential oils and esters. The non-volatile constituents are sugars, acids, pectic substances, gums, nitrogenous substance, mineral salts, sometimes starch, vitamins, pigments, tannins, cellulose, and other substances. The proportion of these constituents varies greatly (*a*) in different fruits, (*b*) in different varieties of the same fruit, (*c*) in the same variety at different stages of ripeness, (*d*) with climatic and soil conditions, and (*e*) with the time and condition of storage. The principal fruit acids are citric, malic, and tartaric.

Pectic substances in fruits. In the early stages of fruit development, the protopectin, which is the parent pectic substance that does not form a sol with water, is the chief pectic substance. Protopectin (26) is readily acted upon by a long list of reagents and treatments that degrade it to pectin which forms a sol with water. Protopectinase converts protopectin to pectin during the ripening of the fruit. Heating the fruit also converts the protopectin to pectin. This is largely due to the acidity of the fruit juice. De-esterification of the methoxyl groups occurs gradually. In very overripe fruit, the pectin has been largely converted to pectic acid.

Fruits used for jelly and jam. The term jelly as used herein refers to a table jelly made from strained fruit juice. Standards have been set for commercial jelly by the Food and Drug Administration. Gel is a more general term. Jams differ from jellies in that they contain the crushed fruit pulp. Otherwise the discussion for jellies is applicable to jams.

Any fruit juice or pulp can be used to make jelly or jam with the addition of pectin and adjustment of the *p*H and sugar concentration. Some fruits contain sufficient pectin and are sufficiently acid so that all that is needed to make jelly from the juice is to add the right proportion of sugar nd cook. Unless they are overripe, the following fruits fulfill these requirements: tart apples, blackberries, crabapples, cranberries, currants, ooseberries, grapes, quince, and sour plums. Oranges contain enough ectin, but not always enough acid. The juice from sweet apples, apricots, herries, strawberries, pears, peaches, figs, and huckleberries is lacking either n quantity or quality of pectin. In some of these fruits the amount of acid s also insufficient.

Home extraction of juice. It is necessary to heat the fruit for the xtraction of pectin. Juice from uncooked fruits will seldom gel or yields jelly of poor quality. The reason is that the protopectin is not soluble n the juice. If the juice is extracted from raw fruit the protopectin renains with the pulp, but if heated the protopectin is converted to pectin.

With most fruits the minimum of water is used for pectin extraction. Excess water dilutes the pectin, and long boiling to evaporate the water reduces its jellying strength. Hard fruits like apples, crabapples, and quinces are cut into small pieces or ground with a food chopper to increase the area for extraction of pectin. Since the skins and cores contain a large proportion of pectin these fruits are not peeled or cored. This ground material is usually just barely covered with water. Soft fruits are crushed. A general rule for soft fruits is to add ¼ cup of water to each pound of fruit, but the best proportion of water varies widely. Underripe fruit or fruit deficient in normal amount of juice in drought seasons may require a higher proportion of water. Gooseberries, if green, owing to their very high acid and pectin content will need rather large quantities of water. Ripe gooseberries are treated the same as other berries.

Apple juice, particularly that from underripe fruit, sometimes contains starch, which causes the jelly to appear cloudy or opalescent. Askew (1) states that starch formation begins near the periphery and progresses toward the core; but as the fruit matures the core area is cleared of starch first, the area near the skin last. Commercially, diastase is often added to convert the starch to sugar and thus clear the juice. Baker (3) states the optimum conditions for removal of starch from pectic extracts and apple pomace.

Grape juice contains tartaric acid, which often crystallizes in long needlelike crystals in the jelly. Part of the acid can be removed by putting the juice in a refrigerator (the colder the better as the acid is less soluble at lower temperatures) overnight or for a few days, and then straining the crystals from the juice.

Theory for Jelly Formation

Spencer's (43) theory for gelation of pectin gels, stated briefly, is as follows. A pectin sol is stabilized by hydration and a negative charge on the pectin particles. The greatest stability comes in the neutral range as increasing alkalinity or acidity decreases its stability. In jelly the sugar has the role of a precipitating agent; the more acid the solution, the less sugar is required for precipitation of the pectin. Salts may aid or hinder precipitation, depending on whether they increase or decrease the stability of the pectin.

Olsen (36) summarizes the theory of jelly formation as follows: Granted that pectin is a negatively charged hydrophilic colloid, the following may be assumed: (*a*) sugar is the dehydrating agent; (*b*) the hydrogen-ion concentration reduces the negative charge on the pectin, thereby permitting the pectin to precipitate and coalesce in the form of a network of insoluble fibers, provided that the concentration of sugar is sufficient; (*c*) the dehydration of the pectin micelles by sugar is not instantaneous but requires time to come to an equilibrium; (*d*) the rate of dehydration and precipitation increases in direct ratio as the hydrogen-ion concentration; (*e*) the maximum jelly strength is reached when the system reaches equilibrium; (*f*) any component added to a pectin jelly system, including salts, which causes a change in the ultimate jelly strength of that system may function either (*i*) by changing the rate of gelation, or (*ii*) by affecting the ultimate jelly structure, or (*iii*) by a combination of these two.

Speiser et al. (42) think that the long polymer chains of galacturonic acid are cross-linked with secondary valences or ionic bonds to form gels. In 65% sugar gels the active links are the hydrogen bonds. These hydrogen bonds are formed through the sugar molecules. This theory is similar to that for gelation of gelatin gels. It can account for both the setting and melting of the gels. The hydrogen bonds break readily so that the gels are easily deformed and are relatively inelastic. The calcium-ion bonds between carboxyls are the most effective cross links in low-methoxyl calcium pectinate gels. Since the bond distances are short, the pectin molecules are close together at these cross links. The resulting gels are more inelastic and brittle, with less recovery after deformation, although their strength may be as great as or greater than the high sugar gels.

The Role of Pectin in Gel Formation

The formation of a gel is dependent upon the pectin added to or found in the fruit juice. The strength of the pectin gel varies with the concentration of the pectin, the *p*H, the sugar concentration, and the salts present. Gel strength is also affected by the gelation temperature and the time elapsing between completion of cooking and the pouring of the gel mixture.

Concentration of the pectin. Pectin cannot be considered alone, since its setting is also dependent upon *p*H and the sugar concentration. These will be considered later. Other things being kept constant, the stiffness of the gel increases with increasing concentration of the pectin up to a certain point, when the addition of more pectin has little effect. There must be sufficient pectin so that the molecules are continuous. Too little pectin gives a soft sirup instead of a gel. Varying amounts of different pectins may be required to give a gel of definite strength owing to differences in the size of the pectin molecule and to other factors.

Joseph (22) states that a sol of 0.3–0.5% pectin will not gel when chilled, but, if sugar is added to 60–65% of total weight and the *p*H adjusted to *p*H 2.0 to 3.5, a gel forms quickly, sometimes near the boiling point when rapid-setting pectins are used. He gives the approximate amount of pectin for various types of gels as 0.1–1.8% but adds that the amount of pectin is often not as important as the technic used. Homemade jelly usually contains from 0.75 to 1.0% pectin. Commercial jelly, on account of shipping, is usually stiffer, and may contain as much as 1.25% of pectin.

Temperature of gelation. Investigators have shown that when gelation starts at a high temperature, *i.e.,* when the dehydrating agent sugar and the pectin are combined and boiled, the strength of the resulting gel is much less than if these ingredients are combined at 70°C or a lower temperature. Hinton (19) combined ingredients at 70°C. Olsen (36) used 55° as well as boiling temperatures. Olsen shows that the gel structure obtained at the lower temperature differs from that formed from the boiled mixture. The pectin from jellies made at 50° and 100°C (total heating time about 4.75 minutes) was recovered, and both samples made into jellies at 50°C. The pectin recovered from the jelly initially made at 100°C produced as strong a gel as that recovered from the jelly made at 50°C, and both gave as strong a gel as the pectin originally used at 50°C. This indicates that the decrease in jelly strength at the higher temperature is not due to destruction of the pectin but to differences in the pectin network forming the jellies. It also shows that only a small fraction of the gel-forming property of pectin is utilized by the ordinary methods of preparing jellies.

In this connection it is interesting that some homemakers use a method of combining sugar with juice that utilizes the greater strength of the pectin when combined with sugar at a lower temperature. Juice extracted from ripe grapes, ripe blackberries, or other ripe fruits has a smaller proportion of pectin but a better fruit flavor than juice extracted in a similar manner from underripe fruit, the pectin often being insufficient to yield a jelly by the "boiling" method. The warm juice is poured into a jelly glass. To this juice sugar sufficient to compose about 60–65% of the finished product is added and stirred until dissolved, then left to gel. The greatest difficulty in using this method is getting all the sugar in solution. Otherwise, it crystallizes in the jelly in a short time.

Rate of gelation. The rate of gel formation depends upon many factors, the type and amount of pectin, the *p*H, sugar concentration, and temperature. With a given quantity of a specific pectin the gel forms faster as the *p*H is lowered.

The rapidity with which gelation starts may affect the strength of the jelly. If gelation is started before the jelly is poured, the mechanical disruption caused by pouring lessens the gel strength. This is shown by the data of Olsen (36), Table 15.

TABLE 15

The Relation of the Time Factor to Optimum Acidity

The time indicated is the interval between the pouring of the pectin solution into the sugar sirup and the pouring of the mixture into glasses. Jellies contain 60% of sugar, 2.5 grams of apple pectin 119°F, phosphoric acid as indicated. Temperature of pectin solution 36°C; of sugar solution 65°C; of final mixture 55°C (*Olsen*).

25% phosphoric acid solution cc	Series B 90 seconds		Series C 50 seconds		Series D 8 seconds	
	Jelly strength	*p*H	Jelly strength	*p*H	Jelly strength	*p*H
0.26	....	....	0.0	3.27	....	....
0.36	33.0	3.10	....	....	36.5	3.13
0.56	69.0	2.80	....	....	67.0	2.88
0.86	....	....	80.0	2.50	....	....
0.96	41.0	2.39	....	....	115.0	2.40
1.06	....	....	75.0	2.37	....	....
1.26	....	....	61.5	2.24	....	....
1.56	19.0	2.13	....	....	120.0	2.13
1.96	14.5	2.03	28.5	2.00	145.0	2.01
3.96	....	....	....	....	135.0	1.76

Length of heating the pectin. Many investigators (19, 26, 32) have found that high temperatures decrease the strength of pectin gels, the loss in gel power increasing as the heating time is lengthened. This is in agreement with the effect of extraction temperature on pectin strength. Baker and Goodwin (7) found that the gel strength of two varieties of cranberries was 57 and 52 (centimeters of water pressure) when boiled 2 minutes, whereas the gel strength was 26 and 17 centimeters when boiled 7 minutes. Bennison and Norris (8) found that no autoclaved pectin will produce a gel.

Hinton (19) increased the hydrogen-ion concentration eightfold and showed that the loss of gel strength comes from the heating and not from the acidity.

Some of Tarr's data (44) indicate that if the sugar is in the juice during the boiling period it protects the pectin. These results, Table 16, show that the decrease in gel strength is considerable when the pectin and acid are boiled before the sugar is added. Baker and Goodwin (7) found that sugar does not protect cranberry pectin from loss of gel strength.

Household tests for pectin in fruit juice. There are three household methods for testing the amount of pectin in fruit juice. One is to cook a small portion of the juice with sugar to see if it will form a jelly. The other methods are to test the juice with alcohol or to test its viscosity.

TABLE 16

THE EFFECT ON JELLY STRENGTH OF BOILING THE PECTIN WITH ACID PREVIOUS TO ADDING THE SUGAR (*Tarr*)

Time of boiling pectin and acid, minutes	Time of boiling pectin, acid and sugar, minutes	Jelly strength, pressure in centimeters of water	
		Top	Bottom
0.0	19.4	61.5	79.5
1.0	19.2	58.0	77.5
2.0	19.5	58.5	76.5
3.0	17.2	57.5	73.0
4.0	17.5	55.5	70.5
6.0	13.2	49.5	67.5
8.0	11.0	44.0	62.0
10.0	9.0	41.0	58.5
11.3	6.3	39.5	54.5
12.0	6.3	33.5	49.0

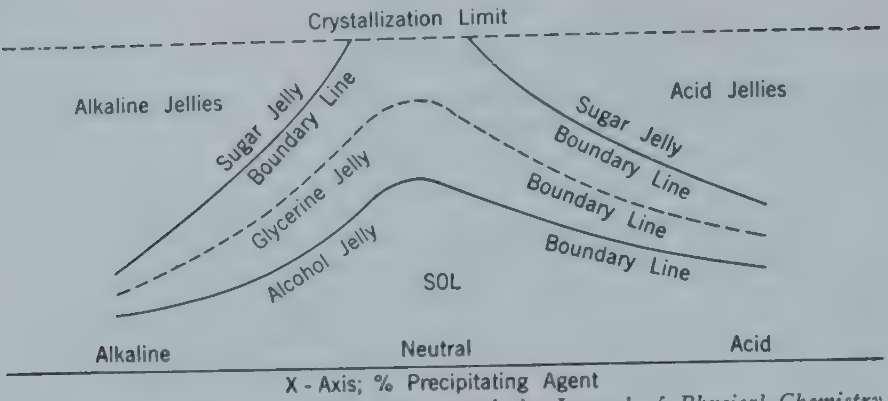
Alcohol precipitates pectin in a jelly-like mass. About 1 part of juice to 3–5 parts of alcohol is used. If the pectin comes down in a solid mass there is a sufficient quantity to make jelly. If the pectin is flocculent or in very small flakes the juice needs additional pectin.

Viscosity. Myers and Baker (32) observed early in their work with pectins that the gel strength of pectin is related to the viscosity of the juice. On the basis of the observed correlation of the viscosity of pectin sols with the gelling power of the pectin extract, Baker (2) developed a jelmeter. The jelmeter is similar to a graduated pipette. The rate of flow of the fruit juice through a given orifice is compared with the rate of flow of an equal amount of water. From the approximate viscosity the amount of sugar to use with a given amount of juice can be determined. Baker has prepared tables for the proportion of sugar and the weight of the finished jelly to use with the jelmeter. The test is easy to make and is practical. The design of the jelmeter has been improved several times.

Jelly test. The jellying stage has been reached when part of the sirup poured from a spoon forms a "sheet" instead of a thin stream.

The Role of Acid in Gel Formation

Pectin can be precipitated over a wide range of *p*H, as shown in Fig. 16*b*. Sugar, glycerin, or alcohol may be used as precipitating agents. Spencer (43) states "The successful making of alcohol jellies requires rapidity of motion and practise, otherwise one obtains a precipitate and not a homogeneous jelly." Gels with sugar as the precipitating agent are not possible in the neutral region owing to the solubility limits of sugar. Alkaline



Courtesy of Miss Spencer and the Journal of Physical Chemistry

FIG. 16*b*. "A qualitative view of the relations of the boundary curves of pectin jelly fields for sugar, glycerine, and alcohol jellies. The alcohol jelly field is the largest, and the sugar jelly field the smallest." From *J. Phys. Chem. 33:* 1993 (1929).

jellies are interesting theoretically, but practically are not important, since they would not be consumed because of their flavor.

Acid is essential in high-methoxyl pectins for gel formation. Early work with pectin showed that with increasing hydrogen-ion concentration jelly strength increases until an optimum is obtained, then with still greater acidity the jelly strength again decreases. From this earlier work the optimum appeared to be *p*H 3.0 to 3.3. Then Olsen (36) showed that with greater hydrogen-ion concentration the jelly strength increases at least to *p*H 2. The loss (36) of jelly strength of other investigators between *p*H 3 and 2 is explained as due to premature setting of the jelly. Hinton (19) finds that, for solutions in which pectin is low or of poor quality, if a gel forms at all it is distinct and measurable at *p*H 2. Hence it can be stated that the greater the hydrogen-ion concentration of the juice the greater the rigidity of the jelly provided that premature gelation is avoided. The fruit juices used for jelly have higher *p*H than 2. Gooseberry juice has been used in the author's laboratory with *p*H 2.5, although the *p*H usually is around 2.7 to 2.8.

Singh (41) has reported that "between certain limits the greater the acidity of the juice the lower the amount of sugar required." Hydrogen (or hydroxyl) ions lessen the stability of the pectin sol by decreasing the hydration capacity of the pectin. Hence in a more acid medium less sugar is required to bring about gelation. Nearly neutral fruit juices will not form jelly with sugar because the sugar is not soluble enough in this *p*H range to precipitate the more stable pectin. Thus with a definite concentration of pectin, and other conditions standardized, the rigidity of the jelly is determined by the sugar and acid concentrations.

Hydrogen-ion concentration. It is the hydrogen-ion concentration and not the total acidity that is important in high-methoxyl pectin gel formation. This is shown by results of Tarr (44). Using the boiling method, he found the minimum amounts of acid for optimum jelly formation varied with the acid used as follows: 8.5 cc of 0.1 *N* sulfuric acid;

27.5 cc of 0.1 *N* phosphoric acid; 22.7 cc of 0.1 *N* tartaric acid; 52.9 cc of 0.1 *N* citric acid; and 583.3 cc of 0.1 *N* acetic acid. The interesting point about these varying amounts of total acid is that all give the same hydrogen-ion concentration, *p*H 3.40. In this study it was found that the minimum *p*H for jelly formation was 3.46.

With different pectin, Joseph (22) found that no gel forms until *p*H 3.6 or lower is reached even if pectin and sugar concentrations are high. Pectin jellies (22) are most stable in the *p*H range 2–4.5. Fruit jellies of *p*H 3.3 to 3.5 require several weeks to reach maximum firmness, which contrasts sharply with gels of low *p*H (5, 22, 26).

Syneresis. Tarr (44) obtained the best jellies at *p*H 3.1. When the *p*H was below 3.1 syneresis or weeping occurred. The occurrence of syneresis in jellies at *p*H below 3.1 varies with the source of the pectin. The author has never seen syneresis with gooseberry jelly, even when the *p*H of the juice is 2.5. Some citrus pectins made into jelly showed no syneresis at *p*H 2.0 or lower. Baker (5) and others in later work state the occurrence of syneresis is related to the strength of the gel. The stiffer the gel, the less the syneresis occurs. Syneresis is probably more common in cranberry jelly than in most fruit jellies. However, syneresis does not occur in the canned cranberry jelly when the cranberry pectin is replaced with other pectin.

Time of gelation. Olsen (36) varied the amount of acid added to a pectin-sugar solution. In addition the time from the moment the pectin solution was poured into the glasses was varied, as shown in Table 15. These data indicate that the rate of gelation is influenced mostly by the hydrogen-ion concentration. This is explained (19) as follows: "The largest or 'optimum' amount of the acid to be used will be that point at which an additional increase in acid will increase the rate of setting to a point where loss in jelly strength due to a disturbance of the jelly in the stirring or pouring exactly balances the strengthening effect of that same increment."

The Role of Salts in Gel Formation

The role of salts in low-methoxyl pectin gels and in precipitation of pectin has been discussed. All fruit juices contain salts of the acids found in the fruit. These salts buffer the solution. Halliday and Bailey (18) have reported that the addition of calcium chloride favors jelly formation, as somewhat lower concentrations of pectin, acid, or sugar are required when it is added. Hinton (19) also found calcium salts to have a beneficial effect on gelation. However, he emphasizes that if carried too far the action of the calcium and other salts in neutralizing the acidity and raising the *p*H may cause a falling off in jelly strength.

Salts of the fruit acids present in fruit juices may repress the ionization of the acid, this effect being greater with weaker than with stronger acids. Pectin (21, 44) also acts as a buffer. Joseph (21) has reported that the *p*H of a jelly may be raised or lowered slightly because of this buffering action during the gelation process. Myers and Baker (31) from Tarr's (44) and their investigations, came to the conclusion that jelly strength is not so sensitive to changes in hydrogen-ion concentration when the jelly is made from highly buffered solutions. They also state that the cation of a salt may supplement the hydrogen ion to a certain extent, but only at definite hydrogen-ion concentrations. No jelly formed with added salts above *p*H 3.6.

The Role of Sugar in Gel Formation

Speiser et al. (42) have indicated that sugar aids in forming hydrogen bonds between pectin molecules, the gel setting when these bonds are formed. Sugar, if its concentration and that of pectin and acid are sufficient, causes formation of the gel. Spencer (43) explains this precipitation as follows: In a pectin sol "an equilibrium is reached between the partial pressure of the adsorbed water" of the pectin "and that in the dispersion medium." When sugar is added to the pectin sol, this equilibrium is disturbed, for when the sugar dissolves it lowers the vapor pressure of the dispersion medium. As a result the pectin particles lose water and are less stable.

Effect of increase of sugar on gel strength. In general, increases in sugar accelerate the gel strength and the setting of the jelly, probably because of increased dehydration, although rate of setting is also modified by other factors, particularly the hydrogen-ion concentration.

When to add sugar in jelly making. As previously stated, Tarr and Baker (45) found that the jellying strength of the pectin is lessened if the pectin is boiled before the addition of sugar. Yet Tarr found that, if the sugar is added to the pectin and acid prior to boiling, the jelly strength is not decreased even when boiled as long as 42.8 minutes. Hence it seems better practice to add sugar to the fruit juice and concentrate it afterwards, if concentration is necessary.

Concentration of sugar in the finished jelly. Jelly, according to reports in the literature, can be made with concentrations of sugar from 40 to 70% of the finished product. However, the jellies of Singh (41) with 40% of sugar were extremely soft. In addition, with sugar at a minimum the pectin and hydrogen-ion concentrations must be high. The average percentage of sugar in commercial jelly, unless acidity or pectin is abnormally high, varies from 60 to 65%. The concentration of sugar desirable in the finished jelly varies somewhat with the juice from which the jelly is made. Thus gooseberry juice, which usually has a *p*H 2.6–2.8 and also has a high pectin content, is usually of better texture if the final concentration of sugar is short of or about 60%. Cox (10) states that for cranberry sauce too stiff a jelly can be prevented by stopping the boiling process when the sugar concentration is below 60%. The premature gelation (10) can be brought about by too much pectin, acid, or sugar, or all three. For some fruit juices Tarr and Baker (45) have found that 70% of sugar in the finished product gives a jelly of good texture. With higher concentrations than 75% the sugar may crystallize.

Proportion of sugar. The proportion of sugar that can be added to obtain jelly varies with the amount of pectin in the juice, the pectin strength, and the hydrogen-ion concentration of the juice. Tarr and Baker (45) showed that, if the pectin was kept constant, the amount of sugar could be increased as the *p*H was lowered.

Proportion of sugar and jelly yield in illustrations. In general, other factors remaining constant, the yield of jelly parallels the amount of sugar added. The gooseberry juice for the jellies in the illustrations (Figs. 17 and 18, Experiment 13) is from the same source, so that the pectin content and viscosity of the juice were the same. It should be remembered that, whereas each cup of juice had the same concentration of acid and pectin before the sugar was added, the addition of varying amounts of sugar and boiling to 103°C result in a concentration of 60% of sugar in all the jellies. But the boiling to produce a concentration of 60% of sugar thereby concentrates the pectin and acid. That the acid is more concentrated in the jelly from which most water is evaporated is also shown by the taste. Although all jellies cooked to a temperature of 103°C have the same proportion of sugar, those from which the most water has been evaporated are the sourest. There is a proportion of sugar that produces the best jelly for the particular juice used. With increasing amounts of sugar beyond the proportion that yields an optimum jelly, the jelly becomes softer until

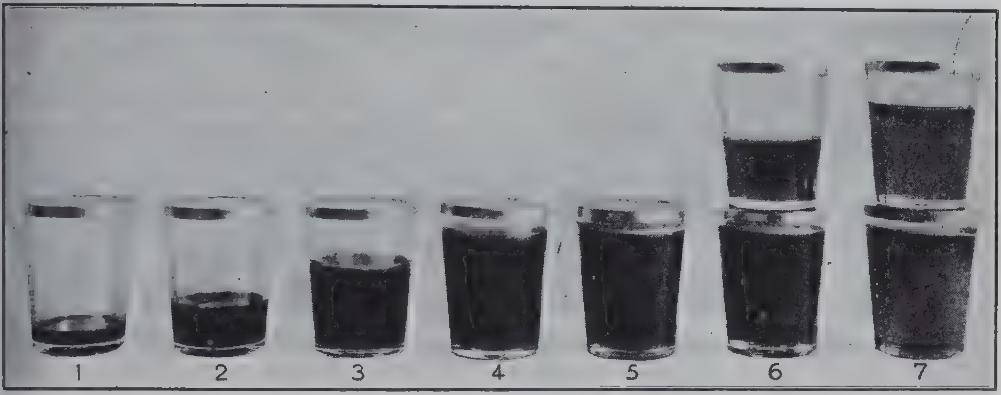


FIG. 17. The yield of jelly obtained when the proportion of sugar to juice is varied. Experiment 13.

1. Jelly made from 2 cups of juice without added sugar.
2. A cup of juice and ¼ cup of sugar.
3. A cup of juice and ½ cup of sugar.
4. A cup of juice and ¾ cup of sugar.
5. A cup of juice and 1 cup of sugar.
6. A cup of juice and 1¼ cups of sugar.
7. A cup of juice and 1½ cups of sugar.

a proportion of sugar is finally reached that results in a fluid sirup instead of a gel.

It is interesting that with a first extraction of gooseberry juice, owing to its high initial pectin and hydrogen-ion concentrations, even the jelly made with 1.5 cups of sugar added to 1 cup of juice is usually quite acceptable as an edible jelly. Very few naturally extracted fruit juices could stand this high a proportion of sugar without producing a sirupy gel. Besides the variation in pectin and hydrogen-ion concentrations in the finished jelly, the other variable for Experiment 13 is the length of the boiling period. Longer boiling is required to evaporate enough water for part 1 (¼ cup sugar to 1 cup of juice) to give 60% of sugar in the finished jelly than in the parts of the experiment wherein a larger proportion of sugar is added to each cup of juice.

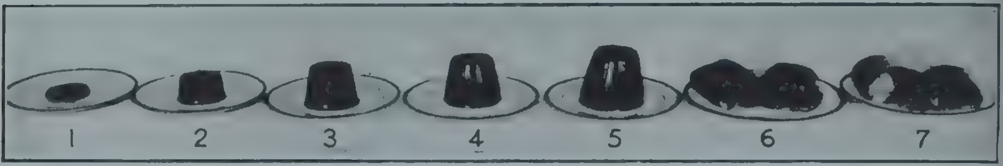


FIG. 18. Showing consistency and yield of jelly from Fig. 17. Jelly made from first extraction of gooseberry juice.

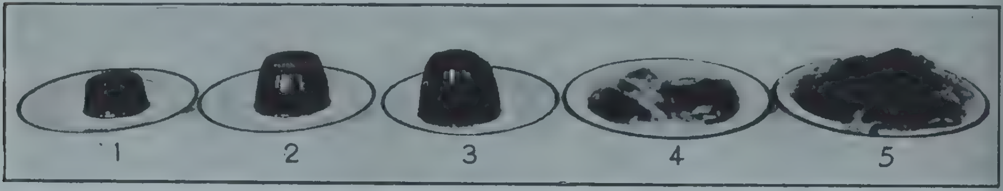


FIG. 19. The jelly from the second extraction of gooseberry juice is softer than the jelly from the first extraction with corresponding amounts of sugar.

1. A cup of juice and ¼ cup of sugar.
2. A cup of juice and ½ cup of sugar.
3. A cup of juice and ¾ cup of sugar.
4. A cup of juice and 1 cup of sugar.
5. A cup of juice and 1¼ cups of sugar.

Proportion of sugar for homemade jelly. The optimum proportion of sugar to add to a given amount of juice cannot be given definitely for the best texture of jelly, since it varies with the pectin, hydrogen-ion concentration, and the salt content of the juice. The amount of pectin varies with the method of extraction, the ripeness of the fruit, the quantity of water added for extracting the juice, and the kind of fruit. Goldthwaite (15, 16, 17) states that it is better to use too little sugar than too much with fruit juices. She has found with all kinds of fruit juices and average methods of extraction that ¾ cup of sugar to a cup of fruit juice usually gives better results than a cup of sugar to a cup of juice. The author's laboratory and home results agree with those of Goldthwaite. Currants, if not very ripe, need a larger quantity of sugar, unless a large quantity of water has been added for extracting the pectin. Since gooseberries are nearly always picked while they are green, the pectin content of the juice is unusually high, and 1 cup of the juice, unless diluted greatly, requires more than ¾ cup of sugar.

Inversion of sugar in jelly making. The saturation point of a sucrose solution at 20°C is 67%. Thus jellies containing more than 67% of sucrose at 20°C are supersaturated, unless something has happened to the sugar. The pectin tends to keep the sugar from crystallizing, acting as a protective colloid. But even this protective action would not always be great enough to keep the sugar from crystallizing when the concentration of sugar is increased to 70% or over. When sucrose is heated with acid, some of the sucrose is inverted to dextrose and levulose. The amount of inverted sugar formed during jelly making depends upon the hydrogen-ion concentration of the fruit juice and the time of boiling with sugar. Since with inversion there are three sugars in the finished jelly the total sugar that can be held in the finished jelly without crystallization occurring is increased. Tarr and Baker (45) found that, in a solution containing sucrose, dextrose, and levulose, the total maximum solubility is obtained with the proportions of each sugar shown in Table 17 (obtained from the National Bureau of Standards).

TABLE 17

TOTAL MAXIMUM SOLUBILITY WITH CANE SUGAR AND INVERT SUGAR
(*Tarr and Baker*)

Temperature, °C	Grams of cane sugar per 100 grams solution	Grams of invert sugar per 100 grams solution	Grams of water per 100 grams solution
20	37.1	38.6	24.3
25	35.7	41.4	22.9
30	33.4	45.6	21.0

At 20°C, if inversion has occurred to obtain maximum solubility, about 75.7% of sugar is soluble. Thus jelly containing about 70% of sugar is not necessarily supersaturated. The salts and organic constituents of the fruit juice may also increase the solubility of the sugar in a given solution.

Rate of inversion in different fruit juices. Tarr and Baker (45) have determined the rate of inversion of sucrose during jelly making with equivalent solutions of sulfuric, tartaric, and citric acids. As would be expected, they found the inversion to be greater with the more highly ionized acid. Longer heating with a given hydrogen-ion concentration also increased the amount of inversion.

Tolman, Munson, and Bigelow (47) in 1901 obtained results, which we are now able to interpret on the basis of our present knowledge, on the inversion of sucrose by juices of different fruits. Their work was published before hydrogen-ion concentration was thought of in connection with jelly making. After determining the amount of invert sugar in a series of jellies and jams that they had made, they concluded that the inversion of the sucrose varies with the total amount of free organic acid present and the length of time the product is heated. But they found some exceptions to their conclusions. Crabapple jelly with 0.17% acid (such as sulfuric) gave an inversion of 58.8% of the sucrose, whereas orange jelly of the same acidity gave only 4.9% of sucrose inverted. Since the inversion is in proportion to the hydrogen-ion concentration if time of heating is constant, the greatest inversion occurred with the acid giving the highest hydrogen-ion concentration, the tartaric acid of the grape. In this instance the total acidity was higher too. Plum with a high total acidity of 1.35% yielded a lower percentage inverted than the grape with a total acidity of 0.69%. The plum contains malic acid, which would result in a lower hydrogen-ion concentration than the tartaric.

Kinds of Sugar Used in Jelly

Most jelly is made with sucrose. There are two sources of sucrose: one, the sugar beet; the other, sugar cane.

Cane or beet sugar. For some unexplained reason many persons believe that jelly cannot be made from beet sugar. Shaw (40) in a series of over 2000 tests found no difference in the two sugars. Lowe and Redfield (29) could detect no differences in jellies made from beet and cane sugar. The sugar was sent from different sections of the state. In these experiments the source and kind of sugar were not known until the experiments were finished.

Dextrose. Crystalline dextrose when substituted by weight for sucrose in a fruit juice yields a jelly similar in texture to that obtained with sucrose, but it is less sweet. At 20°C, a 50% dextrose solution is saturated. When the gel mixture is cooked to 103°C, it contains about 60% of dextrose. Crystals usually begin to form at the top surface of the jelly in 24 hours. When completely crystallized the appearance is similar to flowerets of cauliflower, except they are colored. See Fig. 20. If dextrose is substituted for 50% of sucrose, crystallization may not occur, and if crystals do appear they are slower in forming. About 50% of the jellies made in the author's laboratory with one-half sucrose and one-half dextrose crystallized.

Levulose. Levulose also forms jelly, but it is more likely to be sirupy, and if a jelly is formed the sirup must be boiled to 107°C, which brings the levulose nearer to its saturation point.

Maltose. Maltose has been used by the author for gooseberry and currant jelly. Maltose is considerably less soluble than sucrose and a little less soluble than dextrose at room temperatures. The jelly made with maltose is very tart and crystallizes as readily, or more so, as jelly made with dextrose.

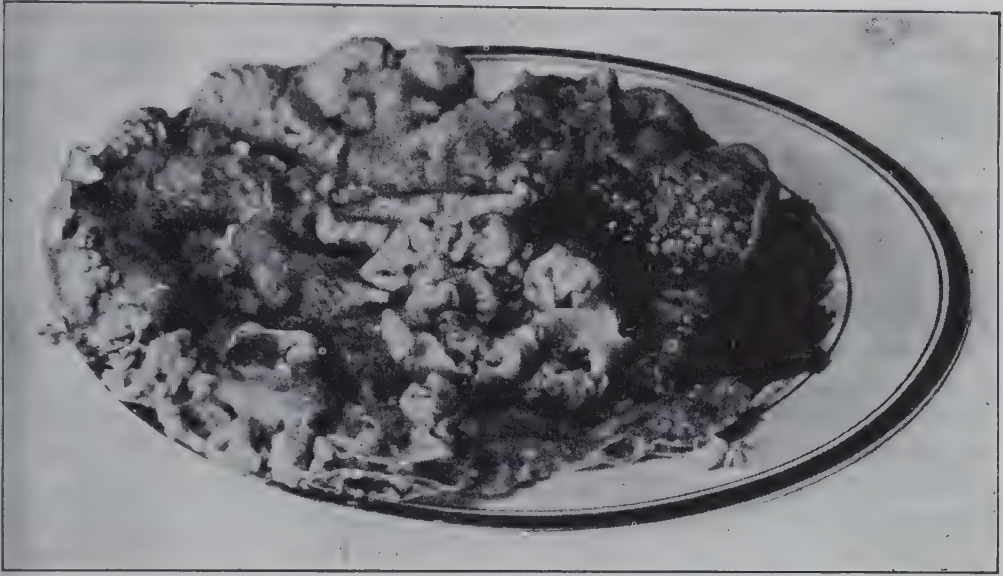


FIG. 20. Jelly made from crystalline dextrose, showing crystal formation 48 hours after the jelly had been turned out of the glass and 72 hours after the jelly was made.

Temperature for Boiling Sirup for Jelly

A 60% sugar solution boils at 103°C, and a 70% solution boils at 106.5°C. See p. 63. A jelly cooked to a temperature between these two temperatures would contain between 60 and 70% sugar. Cruess and McNair (13) have reported that jellies containing amounts of sugar by boiling to 65° Brix give a good concentration for jelly. A solution of sugar of 65° Brix boils at sea level at 103.9°C. These authors suggest adding 3.9°C or 7.02°F to the boiling point of water of any locality to obtain a suitable boiling point for jelly.

The directions in the laboratory outline state to boil the sirup to 103°C. This is for a location where the water boils at 99°C. This gives approximately 60% of sugar in the finished jelly. This is sufficient for juice that contains a high pectin content and a high hydrogen-ion concentration. A juice of low pectin content and higher *p*H may yield a better jelly if boiled to 104–105°C.

Color of Jelly

The color of jelly depends upon the fruit from which the juice is extracted and the length of the boiling period. With longer boiling a darker-colored jelly is obtained. With dark-colored fruit juice further darkening is not desirable, but it may improve the appearance of a very light-colored one. To keep the darkening of the jelly at a minimum it should be made in small lots and boiled rapidly.

The Finished Jellies

The series of jellies made by directions in Experiments 13 and 14 are interesting, since the student can check his accuracy five ways. If no mistakes are made in weighing and the jelly is cooked to 103°C, the finished jellies should have the same percentage of sugar (60%), but should show stepwise increments in yield of jelly obtained, and in stiffness, sourness, and color of the jelly.

Storage of Jelly

Freshly made jelly has a better flavor and aroma than jelly that has been made and stored for some time. The cooking causes some decomposition of flavoring products. On standing, some of the aromatic substances and flavoring substances are volatilized and some are probably lost by decomposition.

Storage, mold, and sugar concentration. With too high a percentage of sugar, crystallization may occur. With too low a concentration, the jelly will mold more readily. It will also ferment more readily than a jelly with a higher concentration of sugar. Singh has reported that jellies made with less than 65% of sugar molded unless the jelly containers were sterilized.

Sterilization of the glasses, and having them dry and hot when the jelly is added, probably aid in preventing mold and also fermentation. Running melted paraffin over the top of the jelly so that it forms a complete seal is an aid in keeping the jelly from spoiling.

Frozen jelly and jam. Jellies, jams, marmalades, preserves, and fruit purees can be frozen without much loss of flavor (11, 12, 20, 37, 46, 48). Crothers (12) stored jellies made from five fruits at −18°C and at room temperature. She found the jellies stored at freezing temperature were tenderer and retained the color and flavor characteristics better than other samples from the same lot stored at room temperature.

Making Jam without Cooking the Fruit

Kramer and Sunderlin (28) have published formulas and directions for making jam from frozen fruits, such as red raspberries and strawberries, without cooking the fruit. Since the jams are not cooked, they have a unique fresh flavor, are easy to prepare, are softer than cooked jams, are very sweet, and must be frozen or refrigerated to keep.

Definition of Jelly

This chapter would be incomplete without giving Goldthwaite's (17) definition of an ideal jelly. "Ideal fruit-jelly is a beautifully colored, transparent, palatable product obtained by so treating fruit-juice that the resulting mass will quiver, not flow, when removed from its mold; a product with texture so tender that it cuts easily with a spoon, and yet so firm that the angles thus produced retain their shape; a clear product that is neither sirupy, gummy, sticky, nor tough; neither is it brittle and yet it will break, and does this with distinct beautiful cleavage which leaves sparkling characteristic faces. This is that delicious, appetizing substance, a good fruit-jelly."

Under the standards promulgated by the Food and Drug Administration (14), fruit jelly must contain 45 parts by weight of a fruit juice or a mixture of fruit juices to 55 parts by weight of soluble solids (sugars). Certain optional ingredients are specified.

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JELLY

Directions for preparing the fruit for jelly. Wash but do not pare apples and crabapples. Remove bad spots and wormy places, but retain the seeds and core, as they contain pectic substances. Cut in rather small pieces, or grind to give a larger surface area for extraction of the pectin. Cover with water, and cook until fruit pulp is soft. Water-packed canned gooseberries are excellent for laboratory use, as they are easily obtained at any time of the year; the number-10 size is the most economical. The juice for water-packed canned gooseberries is not cooked for the first extraction but drained without heating. Usually the juice needs diluting before using for tests. Use the pulp for a second extraction, Experiment 14.

Temperature for cooking jelly. The temperature to which the jelly should be cooked varies with the elevation above sea level. Add 4° to the boiling point of water for your locality. This gives the temperature to which to cook the jelly for 60% of sugar. The temperature given in the experiments is for a locality about 1000 feet above sea level, at which water boils at about 99°C.

Experiment 12.

A. To determine the pectin content of fruit juice.

To 45 or 60 cc of alcohol in a graduate add 15 cc of the juice to be tested. Invert the graduate slowly, and turn back. A precipitate in a mass indicates enough pectin for jelly. Pour out in a dish, and lift the pectin. (See p. 163.) If a quantitative test in desired, follow some standard directions for pectin determinations.

B. Test the juice with a jelmeter. Add sugar and cook according to directions furnished with the jelmeter. Compare the jellies with those made from the same juice under Experiment 13.

Experiment 13.

To determine the effect of varying the proportion of sugar to juice in making jelly.

Use a first extraction of juice. Use 240 grams of juice for a cup and 200 grams of sugar per cup. Add the sugar to the juice, and boil until the temperature is 103°C (217.4°F). Be sure that the temperature reaches 103°C before removing from the stove; read to just above the 103 mark on the thermometer rather than below it. Pour into hot, dry, sterilized jelly glasses. Steriliz glasses by boiling in hot water, then set in a place where they will stay ho before adding the jelly. With more than ¾ cup of sugar to a cup of juice two of the 8-ounce jelly glasses will be needed to hold the jelly. To determine the percentage of sugar in the finished jelly, weigh the pan and spoo before the juice is added. Weigh the pan, spoon, and contents on a balanc as soon as the temperature of 103°C has been reached, then pour into jell glasses. Determine the approximate yield of the jelly in cups by filling othe jelly glasses with water to the same height as the jelly, then measuring th water. This eliminates pouring the jelly into measuring cups and then int the jelly glasses.

1. Boil 2 cups of fruit juice without the addition of sugar until the desire temperature is reached. Does it give the spoon jelly test? Obtain the volume and label it, and set aside to jell. It is best to put this quantity of juice in large pan so that it may boil rapidly, without boiling over. When the juic is concentrated to about ½ cup it may be transferred to a smaller pan, as th quantity of juice at the end of the experiment is so small that it is difficul to get an accurate reading with the thermometer.
2. To 1 cup of juice add ¼ cup of sugar. Cook until a temperature o 103°C is reached. Pour into jelly glass. Obtain volume, label it, and se aside to jell.
3. To 1 cup of juice add ½ cup of sugar. Follow directions under 2.
4. To 1 cup of juice add ¾ cup of sugar. Follow directions under 2.
5. To 1 cup of juice add 1 cup of sugar. Proceed as in 2.
6. To 1 cup of juice add 1¼ cups of sugar. Proceed as in 2.
7. To 1 cup of juice add 1½ cups of sugar. Proceed as in 2. Omit 7 if th alcohol test indicates that the juice is poor in pectin.

Experiment 14.

To determine the effect on the texture of jelly when the juice is not as ric in pectin as in Experiment 13.

To the fruit pulp left from the first extraction of the juice, add water t barely cover, and heat for a few minutes. Drain through a heavy cloth Whatever the percentage of pectin in the juice in Experiment 13, there wil be less pectin in the second extraction. Repeat directions under 13, 2.

1. To 1 cup of juice add ¼ cup of sugar.
2. To 1 cup of juice add ½ cup of sugar.
3. To 1 cup of juice add ¾ cup of sugar.
4. To 1 cup of juice add 1 cup of sugar.
5. To 1 cup of juice add 1¼ cups of sugar.

Compare the resulting jellies with those of Experiment 13.

Experiment 15.

To determine the effect of boiling the jelly to obtain greater concentration of sugar, pectin, and acid.

Use juice from the first extraction. Compare the texture, volume, an percentage of sugar in the finished product with jelly from Experiment 13, 2 with the same proportion of sugar.

1. To 1 cup of juice add ¾ cup of sugar. Cook to 104.5°C (120°F). Proceed as in Experiment 13, 2.

2. To 1 cup of juice add ¾ cup of sugar. Cook to 106.5°C (223.7°F). Proceed as in Experiment 13, 2.

3. To 1 cup of juice add 1 cup of sugar. Cook to 104.5°C. Proceed as in Experiment 13, 2.

4. To 1 cup of juice add 1 cup of sugar. Cook to 106.5°C. Proceed as in Experiment 13, 2.

Experiment 16.

To determine the effect of cooking slowly on the color of the jelly.

1. To 1 cup of juice add ¾ cup of sugar. Cook to 103°C. Cook quickly. Proceed as in Experiment 13, 2.

2. To 1 cup of juice add ¾ cup of sugar. Cook slowly and cook until a emperature of 103°C. Proceed as in Experiment 13, 2.

Suggestions for additional experiments.

Make outline for and use different kinds of sugar in jelly.

CHAPTER
7

Gelatin

Gelatin has been used extensively for experimental work in studying the reactions of colloidal substances, particularly in connection with gel formation.

Uses of gelatin in foods. In food preparation gelatin is used as a basis to make a flavored gel for salads and desserts. It is used as an emulsifying agent, to form a basis for some types of candy like marshmallows, and it is used in frozen desserts.

Source of gelatin. Gelatin is obtained from collagen by hydrolysis. Collagen is a protein found in connective tissue, tendons, cartilage, in the organic part of bone tissue, in the inner layer of skin of animals, and in fish skins, scales, and "sounds" or fish bladders. It is not found as a pure substance in these tissues, but in combination with inorganic materials and with other proteins like elastin, mucin, and mucoid. White connective tissue is found between the muscle fibers, in tendons, and in the inner layers of skin. It contains a high percentage of collagen. The jellying of meat broth after cooling is due to the gelatin which has been formed from the collagen of the connective tissue. Sometimes the concentration of the gelatin in the broth is not great enough to bring about the formation of a gel. When pieces of baked fish skins are allowed to cool on the baking pan, they adhere to it quite tenaciously, because of the adhesive quality of the gelatin or glue formed from the collagen of the skin.

Distinction between Gelatin and Glue

Commercially there is little distinction between gelatins and glues, except that edible gelatin is a high-grade product and complies with the pure food laws. It contains only traces of harmful ingredients, and Bogue (4) states that it should be made from "such stock and by such sanitary methods, as not to be objectionable from the ethical point of view." Glue may be made from the same type of stock as the gelatin, but usually no effort is made to remove impurities.

Manufacture of gelatin. In making edible gelatin the stock is or should be selected with greater care than for inedible gelatin or glue. Gelatin is made from bones and good-grade skin stock. Smith (23) reports that bones from mature cattle make the best gelatin, as those from young animals contain too much water. During processing the bones are treated with acid to remove phosphates and mineral salts. The degreased bone with the inorganic salts removed is known as ossein. It contains the collagen. Skins are treated with lime. This causes swelling and solubilizes the mucins, albumins, and globulins. Smith (23) states that maximum swelling occurs at about *p*H 2.4 in acid solution and 12.3 in alkaline solution. Swelling permits the collagen to be hydrolyzed to gelatin at lower temperatures than would otherwise be possible. Depending on the method of extracting, the gelatin is known as limed or alkaline- or acid-extracted.

Market types of gelatin. Gelatin is available in granulated, pulverized, flake, and sheet forms. The granulated is the form most commonly used in the retail trade in the U. S.

Hydrolysis of Collagen

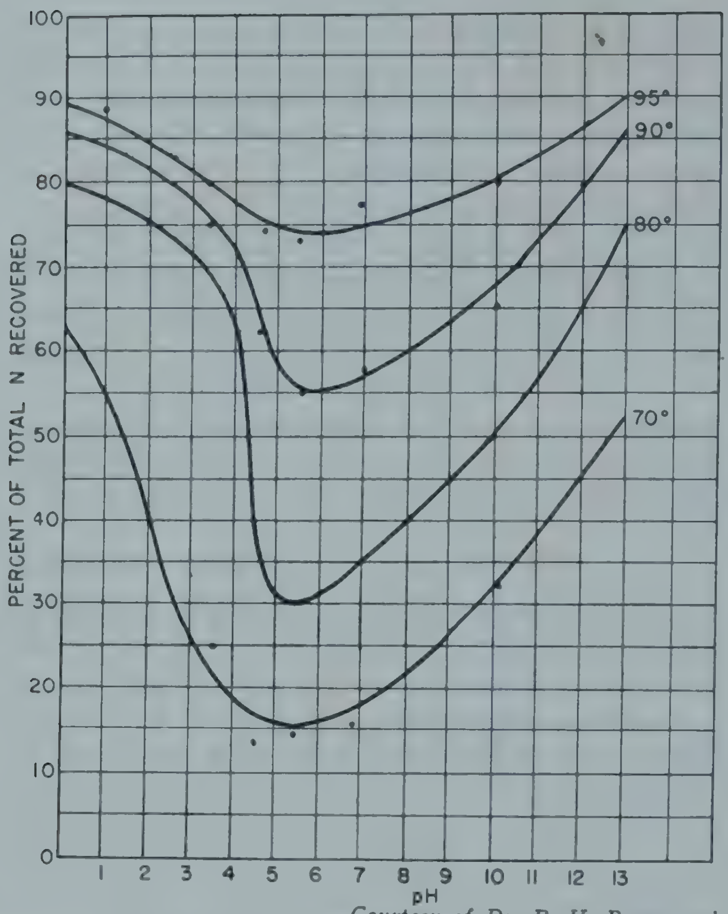
When collagen is heated with water, gelatin is formed. The rate of hydrolysis is modified by the factors hereafter discussed. These factors are applicable to the manufacture of gelatin and to the breakdown of connective tissue in the cooking of meat.

Hydrogen-ion concentration. The effect of varying the hydrogen-ion concentration upon the rate of hydrolysis of collagen to gelatin (5) is shown in Figs. 21 and 22. Bogue (5) used lime-soaked hide pieces for these tests. Throughout the range *p*H 3 to 8 the secondary hydrolysis, the breakdown of the gelatin, is slight. Beyond these limits and particularly with alkalinity of *p*H 11 to 12 the secondary hydrolysis is great.

Temperature. The effect of temperature upon the rate of hydrolysis of collagen, as determined by Bogue (5), is shown in Fig. 21. The rate of conversion increases with elevation in temperature, that at 95°C being least affected by the *p*H of the solution. At the lower temperatures less gelatin is formed in the isoelectric region of the gelatin *p*H 4.5 to 5.5.

Time of heating. Bogue's (5) results, showing the amount of collagen converted to gelatin (tests made at 80°C) with variation in time of heating, are shown in Fig. 22. The drop in the curve at 168 hours is explained as being due to the secondary hydrolysis of gelatin and loss of nitrogen as ammonia.

Agitation and fineness of stock. Bogue's hide stock was cut into pieces about 2 by ½ by ½ inches. With more finely cut stock than that used for the regular studies, the conversion both of collagen to gelatin and of gelatin to its degradation products is increased. When the stock is agitated by passing air bubbles through it at the rate of 10, 4, and 1 per second, designated as rapid, medium, and slow, or zero when no air is used, it is found that increased agitation hastens the conversion of collagen to gelatin but has no effect on the breakdown of gelatin.



Courtesy of Dr. R. H. Bogue and Industrial and Engineering Chemistry

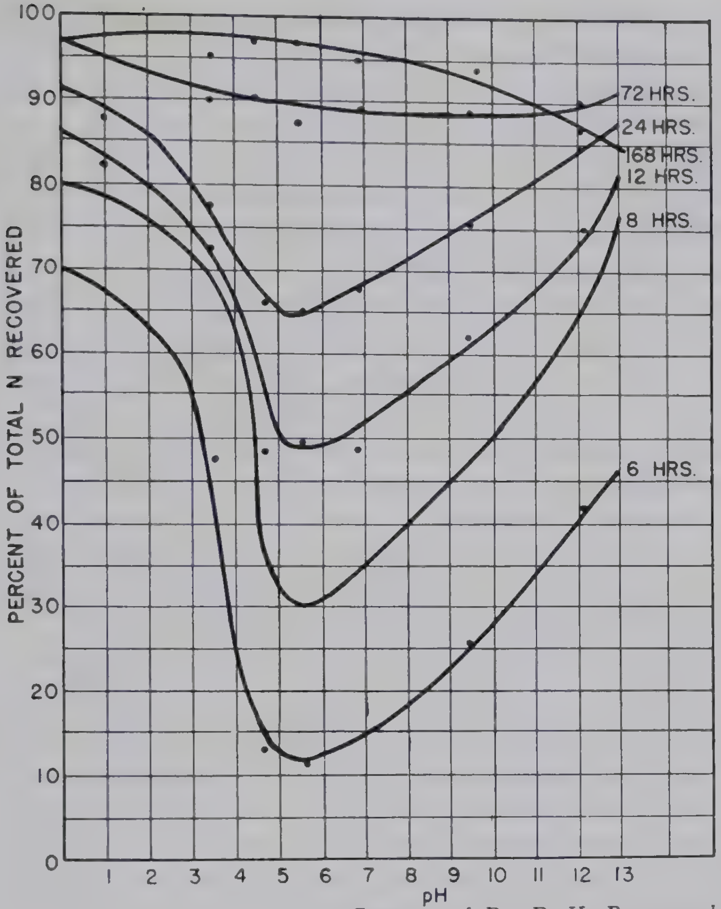
FIG. 21. Hydrolysis of collagen to gelatin: Influence of temperature on total N recovered in the solution at varying *p*H.

The optimum conditions for conversion of collagen to gelatin, *i.e.,* thos by which the greatest amount of gelatin is formed in the shortest time, an during which the least breakdown of the gelatin occurs (5) are as follows a 9-hour heating period at 80°C with the *p*H of the solution between and 4 or between 7.5 and 8.5. The conversion of collagen to gelatin wa at a minimum in the region *p*H 4.5 to 5.5.

Properties of Gelatin

It is possible that there are two types of gelatin. See p. 204. Ames (2 found an anomaly in the middle portion of the titration curves of nativ collagen, which can be explained if collagen is composed of two compounds of similar nitrogen composition. He also found gelatin made fro alkaline-processed collagen had less nitrogen than that from acid-processe collagen.

Gelatin (26) is not a single chemical entity. The source of the gelatin its previous thermal treatment, method of preparation, and other factor



Courtesy of Dr. R. H. Bogue and
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Fig. 22. Hydrolysis of collagen to gelatin. Effect of period of heating at 80°C
total N recovered in the solution at varying pH.

its previous history affect the product. Hence, it is to be expected that
e number of units in a polypeptide chain may vary, and thus cause
ariation in the molecular weight. Ferry (10) concludes that individual
latin molecules vary in size, the larger size reaching a molecular weight
100,000. He states that the larger molecules are not fully extended
polypeptide chains and are not spherical. The shape of the molecule
ay be ellipsoid or coiled, but, if coiled, the coil is longer in one direction.

Isoelectric point of gelatin. Probably no protein has had such a
versity of pH values reported for its isoelectric point as gelatin. Ames
1) by preparing gelatin from various precursors and using both the
kaline and acid process has shown that the isoelectric point depends upon
e pretreatment. By using varying amounts of calcium hydroxide, the
ifting of the isoelectric point was shown to be pH 5.46 to 4.75 in the
kaline treatment. The most exhaustive alkaline treatment, however,
d not cause the pH to fall below 4.75. Ward (26) reports the iso-

electric point of alkaline processed gelatin as *p*H 4.75 to 5.2; that for acid processed as 5.5 to 6.5.

The isoelectric point of natural collagen (1) is *p*H 7.0 to 8.0, but that of alkaline-treated collagen is *p*H 4.8. At the isoelectric point the gelatin is least soluble, least ionized, and swells the least. Bogue (4) found turbidity and foaming ability to be at maximum at the isoelectric point. In fact, cloudiness or turbidity is an almost infallible indication of the approximate position of the isoelectric point.

Swelling. Pulverized gelatin swells more rapidly than the granulated, for, being more finely divided, it has a greater surface area.

The extent to which gelatin swells in water is modified by the surface area; its initial *p*H; the presence or addition of acids, alkalies, and inorganic salts; and its previous history. Bogue (4) states that gelatin tends to absorb water equal to the amount that it held at the last warming, but not much more than this quantity.

In swelling, certain characteristics of the dry gelatin are changed. As its dimensions are enlarged its cohesiveness is lessened. It changes (13) from a hard, brittle substance to a soft, flexible one.

The mechanism of swelling has been the basis for many investigations. Any theory regarding it must take into consideration (13, 14) the structure of the molecule. Although many different suggestions for the structure of gelatin in gels have been advanced, the predominating idea at the present time is that it is fibrillar; *i.e.,* the length of the molecule is many times its width. Long-chain molecules in particular, such as cellulose, starch, pectins, gelatins, and proteins, have the ability to absorb large amounts of water. This water (16, 17) can exist in two states: the bound water associated with certain groups in the molecule, and the free water held in the interstices between the molecules. Katz (13), basing his postulates on x-ray diagram analyses, states that when no change has occurred in the x-ray diagram the water has not penetrated into the interior of the "micelles," and he designates this as intermicellar swelling. When the x-ray diagram is changed to show that the interior of the micelles is enlarged according to the continuous function of the degree of swelling he calls it intramicellar swelling. When a new x-ray diagram forms while the old loses its intensity he concludes that a chemical compound is being formed and designates it as permutoid swelling. Sponsler, Bath, and Ellis (24) from their infra-red absorption studies on the molecular structure of gelatin suggest that swelling is brought about by binding the water to the gelatin molecule through hydrogen bridges. These investigators (24) find the repetition distance, the portion along the backbone allotted to each amino acid residue, to be 2.8 A. The width (side chains) is about 11 A and the thickness about 4.3 A. The repetition distance along the backbone remains the same with varying proportions of water from 0.2 to 90%, showing that the polypeptide chain does not break. The other measurements vary somewhat, but in general the width of the side chains increases with increasing amounts of water. With 0.2, 15, and 33% of water the number of water molecules bound per molecule of gelatin are 4, 260, and 750, respectively. Ferry (10) states that swelling also depends on the concentration of the cross links of the network.

Hydrogen-ion concentration. Loeb (15) states that 1 gram of dry gelatin at the isoelectric point absorbs 7 grams of water but that at *p*H 3.2 to 3.5 it absorbs 35 grams. In general, with increase of hydrogen-ion concentration, absorption of water increases until a maximum is reached. This maximum seems to vary with different gelatins and their preparation, as it is reported by different investigators as being from *p*H 2.6 to 3.5. With still further increase in hydrogen-ion concentration swelling decreases. As the alkalinity is increased, swelling is also increased, the maximum being reached at *p*H 9. With further increase in alkalinity rapid hydrolysis of the gelatin to amino acids and other products occurs.

Salts. Salts affect the swelling of gelatin, some inhibiting and others increasing water absorption. Lloyd, Marriott, and Pleass (14) suggest that the swelling of gelatin in salt solution can be explained by application of Fajan's principle; *i.e.,* salts in which the ions are of equal size and valence are associated with less water than salts in which the ions are unequal in size and valence. Gelatin gels (14) at or near the isoelectric point swell more in salt solutions than in water. The presence of salts in acid solutions of gelatin represses the swelling, which is in accordance with the Donnan theory of membrane equilibrium.

Gelatin sols. In preparing gelatin dishes the gelatin is allowed to swell in a small amount of cold water. To this swollen gelatin hot water is added, or it is allowed to melt over warm water. The swelling increases the ease with which the gelatin forms a sol when the hot water is added, for it is extremely difficult to get the gelatin into solution by adding hot water without previous soaking.

Gelation

One of the outstanding characteristics of gelatin is its ability to form a sol around 35°C or higher temperatures and, with high enough concentration, a gel at lower temperatures. This sol-gel transformation is reversible.

Gelation is the formation of a gel or solidification of a sol. In food preparation this is known as setting of the gelatin. In the sol-gel transformation, changes in the gelatin system occur. These include: changes in viscosity, rigidity, elasticity, optical rotation, surface films, electrical conductivity, and x-ray diagrams. Rigidity is a characteristic common to all gels. During the cooling of the sol, rigidity appears suddenly at the moment of gelation (10). Richardson (21) also comments on the rapidity with which rigidity appears. He states that the acquirement of elasticity distinguishes the gel from a suspension. Although rigidity occurs suddenly, its value does not become constant as it appears, but increases slowly over a long period of time. Heat is liberated with gelation. Ferry (10) states that the change in optical rotation with time very closely follows the rigidity changes. Rigidity (10) is increased with increasing concentration and molecular weight of the gelatin, but over a considerable range of *p*H is independent of hydrogen-ion concentration. Substances that lower the melting point of gelatin also decrease the rigidity.

Hughes (12) has shown that the setting point of the surface film is 2–3° above that of the sol as a whole; *i.e.,* gelation is accompanied by an orientation of the surface layer of molecules. Carpenter, Dahlberg, and Hening (6) have reported that the mutarotation depends to some extent upon *p*H, whether the gelatin is in the sol or gel state, and that equilibrium is not reached at low temperatures for at least 3 days. Taft and Malm (25) find the decrease in electrical conductivity with time to be gradual and regular, indicating that the gelation process is not a discontinuous one but a gradual aggregation of particles. X-ray diagram patterns (14) change during gelation. In the sol state they indicate an amorphous structure, whereas the gel state has the well-defined rings characteristic of crystal structure. In other words, during gel formation a definite orderly arrangement or organization of the gelatin groups has developed in the system.

Viscosity of the sol and rigidity of the gel may run parallel, but this is not always true, for gelatins giving the most viscous sols do not always yield the stiffest gels. Viscosity of gelatin is measured at 35°C by some workers, at 60°C by others. Viscosity is measured by the rate of flow under standardized conditions; rigidity or gel strength is measured after the gelatin has set.

Different brands of gelatin show decided differences in rigidity when made into gelatin dishes. If two gelatins cost the same per pound, one may be more economical than the other, if equal quantities when combined with the same amounts of sugar, water, and flavoring show different stiffening power.

Time, concentration, and temperature all affect the gelation process and the strength of the resulting jelly.

Time of gelation. When concentration and temperature are constant a definite length of time is necessary for gelation to occur. This is characteristic of many colloidal changes. With lessened concentration or a higher temperature a long time is required for setting of the gelatin sol.

Some time may be required after the gelatin sol has cooled to refrigerator temperature before gelation occurs. But, after the gel has formed, its firmness increases with longer standing. Dahlberg, Carpenter, and Hening (8) have reported that, for the weak gelatin solutions used in ice cream, gel formation requires a long time. They allowed 18 hours for gel formation and aging in most of their tests. However, they found that the gumminess in ice cream with too much gelatin increased during 4–5 weeks' storage. They attributed this to the "slow rate at which gelatin gels in weak concentrations come to an equilibrium." Gelatin was shown to possess the ability to reform a gel structure at low temperature after the gel had been destroyed by agitation. This property (8) is not exhibited by agar-agar gels.

Concentration. With a definite temperature and time, solidification occurs only with a definite concentration. With increasing concentration of gelatin the time for setting is shortened. The amount of liquid that a gram of dry gelatin can bind and hold in the form of a gel is high, 1–2 grams forming a gel with 99–98 grams of water.

Ostwald (20) states that the solidification of gelatin in 0.5 hour depends upon the mode of preparation but usually requires about 2% at 15°C and 1% at 0°C. To serve as food the concentration should not be too high, or the jelly is too stiff. Some food gelatins produce a desirable texture for serving with a 1.5% concentration, some require 2%, and some may require as much as 3 or 4%.

It is preferable to use bulk gelatin by weight, rather than by measure. On account of differences in the size of the gelatin particles, a definite measure does not yield the same weight; hence a different concentration of the gelatin would be used.

Temperature. With a definite concentration and time for setting, solidification occurs only with a definite temperature. For a high solidifying temperature a high concentration of gelatin is required. The more slowly a gelatin solution is cooled, the higher the temperature at which it solidifies. A gelatin sol may be cooled, by packing ice around its container, to a temperature below that at which setting would normally occur when a longer time is allowed. On the other hand, gelatin solutions may be mixed and left standing for 2 or 3 hours at room temperature. If they are then cooled rapidly they gel in a short time as if gel nuclei might have started to form while standing at room temperature. At low temperatures all gels become firmer than at higher temperatures. Above 35°C no gel forms with any concentration of gelatin, the sol state occurring at higher temperatures. With the same concentration of gelatin, one sol may gel at 10°C, another at 14–16°C, and still others may require lower temperatures. The ones requiring lower temperatures than 10°C to set do not serve well, for they also soften quickly and at a low temperature.

When gels set slowly at higher temperatures they do not melt as readily as those set rapidly at lower temperatures. One explanation (19, 25) offered for this is that during the longer time required for setting at the higher temperatures orientation of molecules occurs, which is retarded at lower temperatures.

Salts. It has been reported by several investigators that the gelation temperature is affected by electrolytes. The effect is usually given as follows for anions at equal concentrations. The first of the series elevates the gelation temperature, and it is slightly lower for each following anion, until the iodide may lower the gelation temperature below 0°C: $SO_4 >$ citrate

> tartrate > acetate > Cl > ClO_3 > NO_3 > Br > I. This is the order above the isoelectric point. When enough lemon juice or acid has been added so that the reaction is below the isoelectric point the cations may have more effect than the anions.

Dahlberg, Carpenter, and Hening (8) have found that the gel strength is greater in milk than in water, even when the proportion of gelatin added to the milk is based on the water content of the milk and not on its total volume or weight. The change in hydrogen-ion concentration does not account for this increase in jelly strength in all samples. Other factors that might influence the jelly strength are the salt and protein content of the milk. They state that the "influence of salts on gel strength has been observed by other investigators, so it may be one of the means by which skim milk altered gel strength."

Sugar. Friedman and Shearer (11) determined the effect of sucrose, urea, and levulose upon the time of setting in gelatin solutions. They found that small concentrations of these non-electrolytes increased setting time, the maximum being reached at 0.02–0.03 *M*. Concentrations exceeding 0.1 *M* caused the gel to set more rapidly. They also found the diffusion velocity varied directly with the time of setting and concluded that the slower-setting gels had a more open structure. The highest concentration they used was 0.2 *M*. For sucrose this would correspond to about 68.4 grams (about ⅜ cup) to about 1 quart of solution. When lemon juice is used in gelatin dishes, often as much as 1 cup of sugar is added per quart of gelatin mixture.

Reversibility of gelation. When a gel melts the processes for development of rigidity are reversed, but the change occurs more slowly than that produced by cooling (10). The gel may be remelted and solidified many times. A gelatin sol that has solidified and then remelted will form a gel in a shorter time for the succeeding gelations. If some gelatin that has solidified is added to a freshly made gelatin sol, setting takes place more rapidly.

Thixotropy. It is well known (4) that agitation lessens the viscosity of gelatin sols and the rigidity of gels. This property of forming a sol with mechanical agitation, then the reforming of the gel when agitation is discontinued, has been investigated by Myers and France (18). They conclude: "We believe that the solvation of the thixotropic gels by mechanical shear is due to the breaking of the relatively weak hydrogen bonds which hold the lyospheres together. After the shearing stress is removed, there occurs a re-formation of these hydrogen bonds either at the same or different points than was the case previous to solvation." The time required for the gel to reform depends upon the degree of disruption.

Foam formation. Gelatins are often beaten when they have become thick but not firmly set. The beating incorporates air, forming a foam, and the gelatin mixture increases in volume. Bogue (4) states that the ability for gelatin to form a foam is greatest at the isoelectric point. At this point the gelatin particles have a strong tendency to adhere to each other, and this favors foam formation. If the beating is done at the time when the gelatin has set enough to be quite viscid, but has not become brittle, so that the edges break apart, the volume may be increased two or three times that of the original unbeaten gelatin. The lessening of firmness may be partially due to agitation of the gelatin, but part is because of incorporation of air. The gelatin at this stage is elastic and stretches to surround the air particles. The gelatin that is to be beaten should have the flavoring in larger quantity than for an unbeaten gelatin as the increase in volume causes the flavor to seem less concentrated. If gelatin becomes too firm before the beating is started the gelatin only breaks and air is not incorporated. Whipped cream and beaten egg white are often folded into either beaten or unbeaten gelatin.

Opacity in gelatin. Edwards (9) states that two factors of prime importance in gelatin are its strength and the clarity of its aqueous solution. In regard to clarity he says that many perplexing problems occur in this connection, for a gelatin may be clear at one concentration but, if further diluted, may appear turbid. He says that a complete explanation of the problem of turbidity has yet to be made, but some causes are as follows: (*a*) actual dirt, particles of animal tissue and fibers; (*b*) mold; (*c*) emulsified grease and calcium salts of fatty acids; (*d*) protein salts and proteins other than gelatin which precipitate and remain in suspension when the *p*H of the solution is varied; (*e*) a calcium sulfate-phosphate complex which is retained in solution by the presence of sulfurous acid; and (*f*) colloidal sulfur.

Edwards states that the first two difficulties should not be present and when detected the gelatin should be condemned. Emulsified grease is more difficult to remove. It results from the employment of greasy material, extraction of gelatin at the wrong *p*H, the agitation of liquid in the boiling vat, and improper filtration. The presence of proteins other than gelatin is more likely to occur in a skin gelatin. Mucin and chondrin are readily soluble in weak alkalies and are thrown out of solution by acids. Hence they are less likely to be found in acid gelatins. Cloudiness due to the presence of insoluble calcium sulfate-phosphate complex is more likely to be found in ossein gelatins. Colloidal sulfur is more likely to be found in glue than in gelatin stock.

Gelatin is used in the meat trade for packing tongues and chickens and for glazing hams. Sometimes a cloudy precipitate appears which is caused by too much calcium in the gelatin.

Black (3) mentions that unless the copper content of the gelatin is low a purplish discoloration may appear with meats, particularly with chicken and tongues.

Another cause for turbidity is discussed by Clayton (7). At the isoelectric point the gelatin solutions always show more turbidity, a 400%

increase in turbidity occurring with a *p*H variation of 0.03 (*p*H 4.87 to 4.90). Gelatin stock treated with lime shows greatest turbidity on the acid side of the isoelectric point, and, *vice versa,* those stocks treated with acid possess isoelectric points in the region of *p*H 7 to 8.

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GELATIN

Directions for cooling gelatin. The gelatin solutions should be put to cool at the same temperature. Those from the same experiment should be on the same shelf in the refrigerator, as the upper shelves have a higher temperature than the lower ones. A cooling room is a splendid place to put them while cooling. For class work when periods are short the setting may be hastened by putting the containers in crushed ice. The ice should be the same depth around all the containers. It is better to have all the containers for one experiment in the same pan of ice for cooling. The containers should be the same size, shape, and material, for if they are not the same size the surface area for cooling will be greater for some than for others. Enamel or aluminum are good materials for cooling gelatin solutions. Crockery or china cools more slowly than metal.

The proportion of gelatin suggested in the following experiments, 3.5 grams for a cup of liquid, is not the best proportion for all gelatins. With some brands or grades about 2% or about 4.8 grams per cup of liquid will be required for the best results. Find the best proportion of gelatin for the brand that is being used, and substitute that amount for the amount given in the experiments.

Record the time and temperature when the gelatin is mixed, when it begins to gel around the edges, and when set. If cooled in crushed ice, make a record of the temperature every 5 minutes and plot on graph paper. Find the effect on the texture of the gelatin of standing 20 minutes at room temperature. Most gelatins will need to stand at least 20 minutes or longer for serving.

Experiment 17.

To determine the effect of dissolving gelatin by different methods on the time required for setting and the temperature at which gelation occurs.

A. Hydrate 3.5 grams of gelatin with 30 cc of cold water. Add 206.5 cc of boiling water. Stir until dissolved. Record the temperature when the gelatin and water are mixed and the time when they are mixed. Set in crushed ice. Record time and temperature every 5 minutes or more often until set. Plot on graph paper.

B. Hydrate 3.5 grams of gelatin with 30 cc of cold water. Let stand 5 minutes, then melt over hot water. The temperature of the hot water should be 85–90°C. Stir the gelatin until melted, remove from above the hot water, and add gradually while stirring 206.5 cc of cold water. Follow directions for cooling under A.

C. Hydrate 3.5 grams of gelatin with 30 cc of cold water for 5 minutes. Stir while adding 60 cc of boiling water. After gelatin is dissolved, add 131.5 cc of cold water. Follow directions for cooling under A. Compare the length of time required for setting, the temperature at which setting occurs, and the ease of dissolving by each method.

What proportion of an ounce is 3.5 grams? What proportion of an envelope of gelatin? What is the measure in teaspoons? A total of 240 grams of liquid and gelatin is used. What proportion of 240 grams is 15 cc? What percentage is 3.5 grams?

Experiment 18.

To determine the effect of distilled water, fruit juices, tomato, and vinegar upon the stiffening power of gelatin and upon the time required for gelation. Use a plain gelatin.

A. Water.

1. Use the same kind of water throughout a given test. Use tap water. Hydrate 3.5 grams of gelatin with 30 cc of water. Melt by the method found best under Experiment 17. The total amount of water to be added to the hydrated gelatin is 206.5 cc.

2. Repeat 18, A1, but use distilled water.

3. Repeat 18, A1, but use softened water if obtainable.

B. Lemon juice.

1. Repeat A1, but remove 15 cc of water and replace with 15 cc of lemon juice.

2. Repeat B1, but use 30 cc of lemon juice.

3. Repeat B1, but use 60 cc of lemon juice.

C. Grape or other fruit juice.

Repeat B, but use grape or other fruit juice for the lemon juice. For one test use 120 cc of fruit juice.

D. Tomato juice.

Hydrate 3.5 grams of gelatin with 30 cc of water. Substitute tomato juice for the 206.5 cc of water.

Experiment 19.

To determine the effect of varying the percentage of gelatin upon the time required for gelation and the stiffness of the gelatin.

1. Hydrate 3.5 grams of gelatin with 30 cc of cold water. Dissolve by warming over hot water. Add 176.5 cc of cold water, 30 cc of lemon juice, and 50 grams of sugar.

2. Repeat 1, but increase the gelatin to 4.8 grams and reduce the cold water to 174 cc. What is the percentage of gelatin used? Its measure?

3. Repeat 1, but increase the gelatin to 5.8 grams and reduce the cold water to 172 cc. What is the percentage of gelatin used? Its measure?

4. Repeat 1, but increase the gelatin to 7.2 grams and decrease the cold water to 171 cc.

5. Repeat 1, but decrease the gelatin to 2.4 grams and increase the cold water to 192.5 cc.

Experiment 20.

To determine the effect of fresh pineapple on the gelation property of gelatin.

Hydrate 7 grams of gelatin with 60 cc of cold water. Dissolve by warming over hot water, then add 330 cc of cold water, 60 cc of lemon juice, and 100 grams of sugar. Divide into two equal portions.

1. To part one add 2 tablespoons of grated raw pineapple. Cool.

2. To part two add 2 tablespoons of cooked grated pineapple. Cool. Does the gelatin containing the uncooked pineapple gel? Why? What is the effect of cooking upon the pineapple? Results.

Experiment 21.

To determine the effect on the texture of gelatin of beating and the addition of whipped cream and beaten egg white.

Make up 4 cups of lemon jelly by hydrating 14 grams of gelatin with 120 cc of cold water. Dissolve by warming over hot water, then add 720 cc of cold water, 120 cc of lemon juice, and 200 grams of sugar. Divide into 4 equal parts. Metal quart cups are good to use for gelatins that are to be beaten as the volume may be measured without removing from the container.

1. Cool.
2. Cool until it becomes thick enough to beat. Beat with an egg beater until the volume increases. Cool until firm. Obtain volume.
3. Repeat 21, 2, but after beating fold in a stiffly beaten egg white. Cool until firm. Obtain volume.
4. Repeat 21, 2, but after beating fold in ½ cup of whipped cream. Cool until firm. Obtain volume.

Compare for volume, flavor, texture, and number of servings obtained. Does the volume increase or decrease when the whipped cream is folded into the gelatin? Is the above proportion of lemon juice best for both a plain jelly and a beaten jelly? What proportion of lemon juice and sugar would you suggest for a plain jelly? For a beaten jelly?

Suggestions for Other Experiments

1. Compare different brands of gelatin.
2. Use varying amounts of sugar.
3. After hydrating the gelatin, add the water and heat in a pressure saucepan or cooker. Compare with tests under Experiment 17.

CHAPTER

8

Meat and Poultry

Grading and Inspection of Meat

Federal grading and stamping of meat was inaugurated in 1927. Davis (1) states that, because the government is not influenced by season, geographical location, or any other factor, the purchaser is assured, whether by long-distance or over-the-counter sales, of always securing, within certain narrow limits, the same quality of meat when buying a definite United States grade. The service has grown until United States graded meat can be purchased in many though not all retail markets.

Meat animals are divided into groups based upon age, into classes based upon sex, and into grades based upon quality.

Age groups. Bovine animals are divided, because of characteristics at different ages, into veal, calves, and beef. "Typical vealers are less than 3 months of age and have subsisted largely upon milk" (4*b*). "Calves are usually between 3 and 8 months of age" (4*b*).

Ovine animals are divided into lamb, yearlings, and sheep (4*c*). A lamb is usually under 14 months of age, a yearling is between 1 and 2 years, whereas the term sheep refers to ovines over 2 years of age.

There are no standards for the age groups for pork. Pork grades are for the butcher barrows and gilts. Barrows and gilts are usually marketed between 6 and 7 months of age.

Classes of meat. The classes of beef are steer, heifer, cow, stag, and bull. The classes for sheep are ewe, wether, and ram; for pork they are barrow, gilt, sow, stag, and boar.

Two types of grades. Meat may be graded according to Federal or packers grades. Packers use their brand names to designate their better-quality meat. If the United States grade is stamped on the meat, the packer grade is usually omitted, and *vice versa*.

The United States grading is an optional service. The service is paid for by the buyer of the meat. Davis (1) states that the cost of grading varies in different establishments in proportion to the number of carcasses graded and stamped. Grading insures the buyer uniform quality, and both buyer and seller use the same terminology for specifications. In Seattle and in some other cities, all retail cuts must be plainly labeled with the U. S. grade.

Basis for grading. Grading divides, so far as possible, the carcasses of the uncooked meat or subdivisions thereof into groups, the various grades indicating the relative desirability of the meat for ultimate consumption, there being no exact dividing line between one grade and that just higher or lower. The basis for grading is on quality, conformation, and finish of the carcass. Quality so far as appearance can foretell includes relative tenderness, juiciness, and palatability. By conformation is meant the form or shape, animals having broad, large, full muscles, with relatively smaller proportion of bone, being graded highest. Finish refers to the amount, quality, and color of fat within and around the muscle.

U. S. grades. The seven U. S. grades for beef under the former grading system were designated as Prime, Choice, Good, Commercial, Utility, Cutter, and Canner. On January 1, 1951 the new grading system for beef went into effect (4*a*). The former name designations are retained but the Prime and Choice grades are now combined and called Prime, the old Good is now Choice. The former Commercial grade, which contained animals of all ages, has been divided and the younger animals are put into a separate classification called Good. The carcasses from older animals are called Commercial. The Utility, Cutter, and Canner grades remain the same as under the old system. Only beef produced from steers and heifers can qualify for the Prime grade. Hence, there are only six grades for beef from cows, stags, and bulls.

Although, as has been indicated, all the grades may be stamped, in actual practice the bulk of the beef that has been graded and stamped has been the Prime, Choice, and Good grades of steers and heifers. Some Choice cow beef is graded. Very little of the two lowest grades can be purchased on the retail market, since practically all the meat in these two grades, except that for boneless cuts such as tenderloin, is used in products like weiners, bologna, and sausage.

Grades for veal and calf carcasses (4*b*) went into effect March 10, 1951. The grades are Prime, Choice, Good, Commercial, and Utility. Differentiation of calf from veal is made primarily on color of lean (calf is reddish, veal grayish pink). Other factors considered in grading are texture of lean, character and size of rib bones, and carcass weight.

The changes in lamb grades became effective April 30, 1951. The grades are Prime, Choice, Good, Utility, and Cull (4*c*). The former Prime and Choice are combined and called Prime; the former Good is now Choice; the upper two-thirds of the old Commercial grade is now Good; the lower third of the old Commercial grade and the upper two-thirds of Utility are combined and called Utility. The term Commercial is omitted in the new grading system for lamb. The lowest lamb grade, Cull, contains the lower third of the former Utility and the former Cull grades.

The changes in the pork grades became effective in September, 1952. The pork grades for butcher barrows and gilts are Choice No. 1, Choice No. 2, Choice No. 3, Medium, and Cull (4*d*). The grades are based on specifications for the average back fat thickness in inches. The average is obtained by measurements made opposite the first and last ribs and the lumbar vertebra for hogs of varying weights and/or lengths.

Stamping. The stamp indicating the grade has been changed. The letters USDA are at the top within a shield with the grade designation below them. See Fig. 23. The Federal grade stamp is easily identified. It occurs on the meat as a purple, ribbon-like stamp. The material used for stamping is an edible vegetable compound. Stamping starts at the shank of the carcass, continues over the round, the rump, the ribs, and to the neck. On beef a second line is put over the shoulder. The stamp indicating the grade occurs on practically all retail cuts.

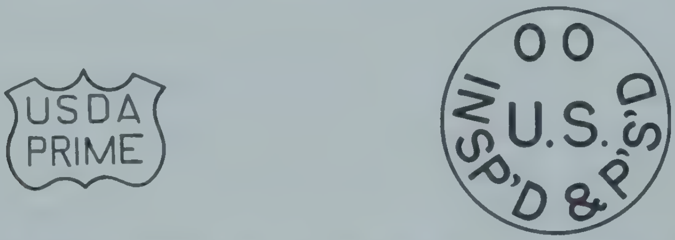


FIG. 23. The Federal stamp used to indicate the U. S. carcass grade is at the left. The letters USDA appear on all grades. The Federal inspection stamp is at right. The two stamps should not be confused: the grade stamp denotes quality, the inspection stamp indicates the meat was wholesome at time of slaughter.

Federal Inspection of Meat

All meats shipped from one state to another are under federal surveillance. This includes the meat produced by the larger establishments, about two-thirds of all the meat that is consumed. Each state and the cities usually have some regulations concerning meats and supervision of local plants.

The purpose of inspection is to insure that the meat sold to the consumer is from healthy animals, in sound condition at the time of slaughter.

The inspection stamp is round. Within the circle are the number of the plant where the animal was killed and the letters "U. S. Insp'd & P's'd." The inspection stamp is placed on each wholesale cut. For example, the wholesale cuts for the hind quarter of beef, the inspection stamp is placed on the round, rump, short loin, and sirloin.

Inspection of carcasses and the supervision of making of meat products safeguard the consumer. However, in one instance, inspection cannot be a complete safeguard. There is no accurate, quick method of inspection that detects trichinae in trichinae-infected pork, though federal supervision does insure that products to be consumed without further cooking are so treated that no live trichinae are present. It should be stated that only a small percentage of pork is infected with trichinae.

Trichinosis. Trichinosis is contracted by eating uncooked, trichinae-infected meat, usually pork. Any animal that eats contaminated pork can contract the disease, and cases have been reported in the medical literature that were traced to the eating of raw, jerked bear meat.

It is assumed that anyone buying fresh pork chops, roasts, etc., will cook the meat. But some people grind raw lean pork, season it, and use it in sandwiches. Others in making homemade sausage taste the uncooked product to see that the seasoning is satisfactory.

Ransom and Schwartz (6) found that live trichinae are quickly destroyed by heating the meat to 55°C. They may be destroyed at 50°C if the meat is held at this temperature for a sufficient time. Ransom (5) found that trichinae are destroyed by freezing, provided that the frozen, infected meat is held at a temperature not higher than −15°C (5°F) for 10 days.

All lean pork, in plants under federal supervision, used with other meat, or in pork products that are to be consumed without further cooking, must be treated to make sure that any live trichinae that may be present are destroyed. Such products include soft or fresh and dry summer sausages, frankfurters and Vienna-style sausages, Italian and Westphalian-style hams, pork butts in casings, cured pork loins in or without casings, capicola, coppa, cotto salami, and other products.

In general the methods used for destruction of trichinae are (*a*) freezing and storage, (*b*) heating, or (*c*) curing of the product according to one of four official methods (2), or a combination of these methods.

The freezing treatment is called refrigeration in packing plants. The lean pork and pork trimmings are frozen to destroy the trichinae. The specifications, based on the work of Ransom (5), allow 10 extra days for a margin of safety, requiring that the frozen meat be stored for 20 days at a temperature not higher than −15°C (5°F).

Destruction of trichinae by heating is called processing. The specifications, based on the work of Ransom and Schwartz (6) and allowing a margin of safety, require that the meat must be heated to 58.3°C (137°F). Some products such as treated sausage may be heated to only 53.3°C (128°F) but must be held at this temperature for a definite time.

Salt treatment is used for some products, but a large amount of salt, 4.5%, is required and a dry cure employed. The meat must be held in this salt cure for a period of 20–25 days at specified temperatures, and further specific procedures must be followed.

Storage of Meat in the Home

Proper storage of meat in the home is often a problem. Halves and quarters of dressed animals have a natural protective skin covering. But when wholesale cuts are divided into smaller parts, the surface area and the chance for contamination both increase as the cut surfaces come in contact with meat blocks, hands, wrapping paper, and kitchen and refrigerator utensils. In general, unless frozen, meat should not be stored long in the home. Low temperatures and dry circulating air increase the storage life of meat. Peet (3) found that roasts keep best, steaks and chops next, and ground meat most poorly.

MEAT CUTS

Meat cuts are composed of muscle, fat, and bone. Hammond (10) states that three main factors affect the proportion of these constituents: (*a*) the age of the animal, (*b*) the plane of nutrition on which the animal has lived, and (*c*) the part of the carcass from which the cut is taken. Connective tissue makes up some part of these three constituents. Bone growth is rapid in the young animal, whereas fat is laid down most rapidly in the older animal.

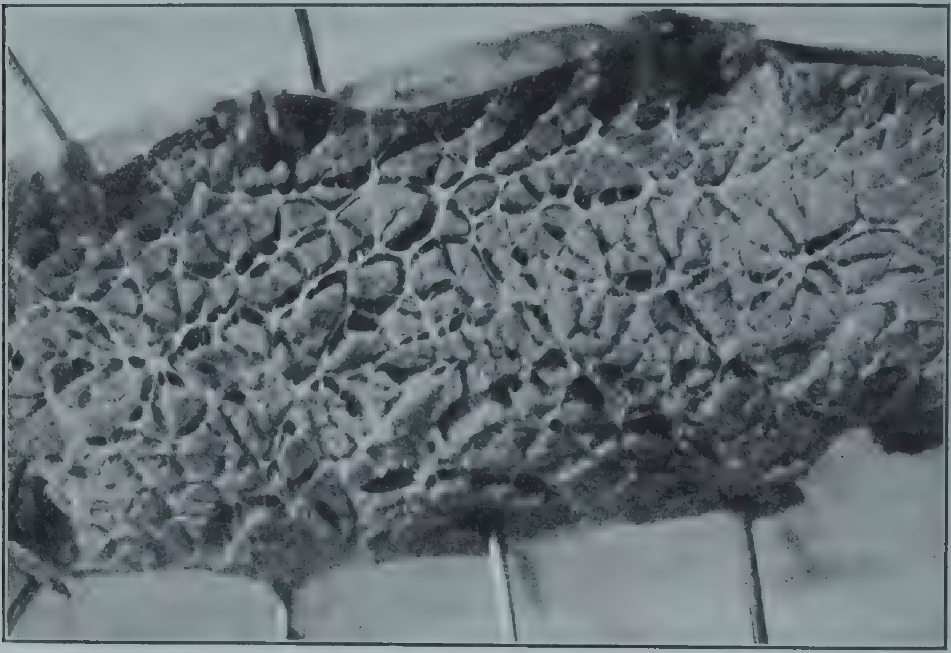


FIG. 24. This photograph shows the bundles of muscle fibers, the fasciculi, and the surrounding connective tissue, the perimysium. Even the connective tissue entering the bundles of muscle fibers is shown in many places. This photograph shows the narrow muscle along the outer edge of a beef rib roast. It was taken after the meat was cooked. The muscle is pulled apart and pinned back. Enlarged about three times.

Skeletal muscle is characterized by response to stimulus. It is an organ made up of fibers held together by connective tissue and surrounded by a sheath of heavier connective tissue. The fibers are grouped parallel to each other in bundles called fasciculi. See Fig. 24. Even the thinner sheets of connective tissue entering the bundle are shown in some portions of the photograph. The connective tissue entering the fasciculi is the endomysium. The size of the bundles or fasciculi varies in different muscles and determines to a certain extent the grain of the meat.

The connective tissue surrounding the fasciculi, the perimysium, varies in thickness, being quite perceptible to the eye in some muscles, as in the outer muscle of prime ribs shown in Fig. 24. In some muscles it is scarcely discernible. The connective tissue enclosing each muscle is known as the epimysium or muscle sheath.

The spaces between the muscles, the fasciculi or the cells, are referred to as intermuscular, interfascicular, or intercellular; the area within the muscle, the fasciculus or cell, is called intramuscular, intrafascicular, or intracellular.

Classes of muscles. Muscles are divided into two groups: the skeletal, voluntary, or cross-striated; and the smooth, plain, or long-striated. The smooth muscles occur in the walls of the hollow viscera, *i.e.,* the intestinal tract, the arteries, veins, etc. Heart muscle is cross-striated but in many of its characteristics it falls between the two groups, voluntary and involuntary.

Variation in muscles. The muscles in the body of an animal are not exercised or used equally. Thus "tender" and "less tender" cuts are obtained from the same animal.

Hiner and Hankins (39) from work on fifty-two carcasses from animals of varying ages divided the muscles within a given carcass into four groups as follows, the tenderness of each group increasing in the order given: (*a*) neck and foreshank, (*b*) round, (*c*) rib, shortloin, loin end, chuck at third rib and across humerus bones, and (*d*) the tenderloin.

The classification of Hiner and Hankins appears to be a better one than the division into the two groups, less tender and tender. Muscles not only have varying degrees of tenderness but also differ in many other respects. Muscles differ in shape, weight, fat content, collagen content, elastin content, and some differ in color. The texture or grain of muscles varies. This is caused principally by difference in the size of the fasciculi and the amount of connective tissue. In addition, the microscopic appearance of fibers in some muscles differs decidedly from that of fibers in other muscles.

Ramsbottom and Strandine (41, 42) have reported the identification and the comparative tenderness of fifty of the larger muscles of beef. They recommend, so far as possible, the separation of the tough and tender muscles for cooking purposes.

Fat and Adipose Tissue

Any of the connective-tissue cells may contain small globules of neutral fat, but the true fat cells have a definite function, the storing of fat. Small spheres of fat globules are gradually added throughout the cell, and these combine to form the adult cell, in which the cytoplast and nucleus are pushed to one side. The shape of the fat cell is spherical, but, when the cells accumulate in large masses, becoming packed together and crowding out other cells to form the adipose tissue, the shape is often polyhedral.

Size of the fat cells. The size of the fat cells varies with the nutritive state of the animal. Hammond (9) states that they may be 10–20 μ in a starved animal, 50 μ in one in ordinary condition, and up to 175 μ in a very fat one. The cells are smaller within the connective tissue and in the marbling fat within the muscles, and larger around the internal organs and subcutaneously.

Deposition of fat. Adipose tissue contains numerous blood vessels and connective tissue. Many fat cells are first laid down adjoining these blood vessels. See Fig. 25. Adipose tissue contains water, the proportion varying under different conditions. The proportion given by different investigators varies from 15% to more than 50% of the fresh tissue. Callow (7) found the water content of fatty tissue of cattle and lambs to be 81–82% on a fat-free basis.

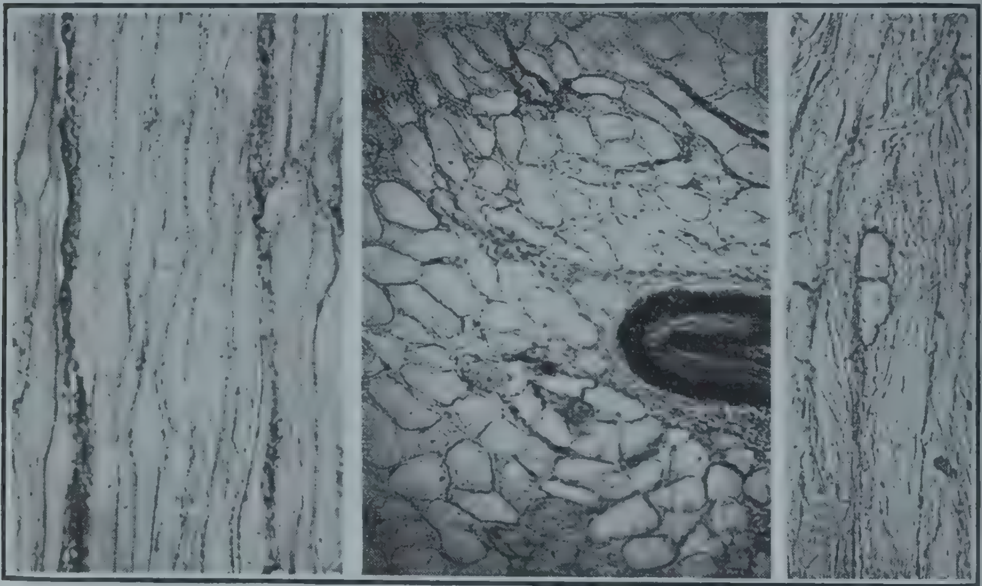


FIG. 25. Fat cells. *Left:* the stained fat cells appear like black dots between the fibers and the fasciculi of the gluteus primus of chicken thigh. This is a 4-hour aged sample and has many rigor nodes. Magnification x 54. *Middle:* adipose tissue of beef, fat cells laid down around a blood vessel. Semitendinosus muscle. Magnification x 54. *Right:* 2 fat cells in beef connective tissue from semitendinosus muscle. Magnification x 100.

Fat tends to be deposited first around the internal organs and subcutaneously. Deposition around and between the muscles comes next. Finally fat is deposited intramuscularly. Most of the intramuscular fat is first deposited between the fasciculi as shown in Fig. 26. Next comes deposition between a few or many muscle fibers. The amount of fat deposited between the muscle fibers varies in different muscles. Hammond (10) states that the neck and thorax muscles have a high fat content interspersed between the muscles, whereas the leg has the least. When in sufficient quantity to be seen without magnification, the intramuscular fat s known as marbling. Fat is liquid or semiliquid in the body and forms soft pads between the organs and muscles.

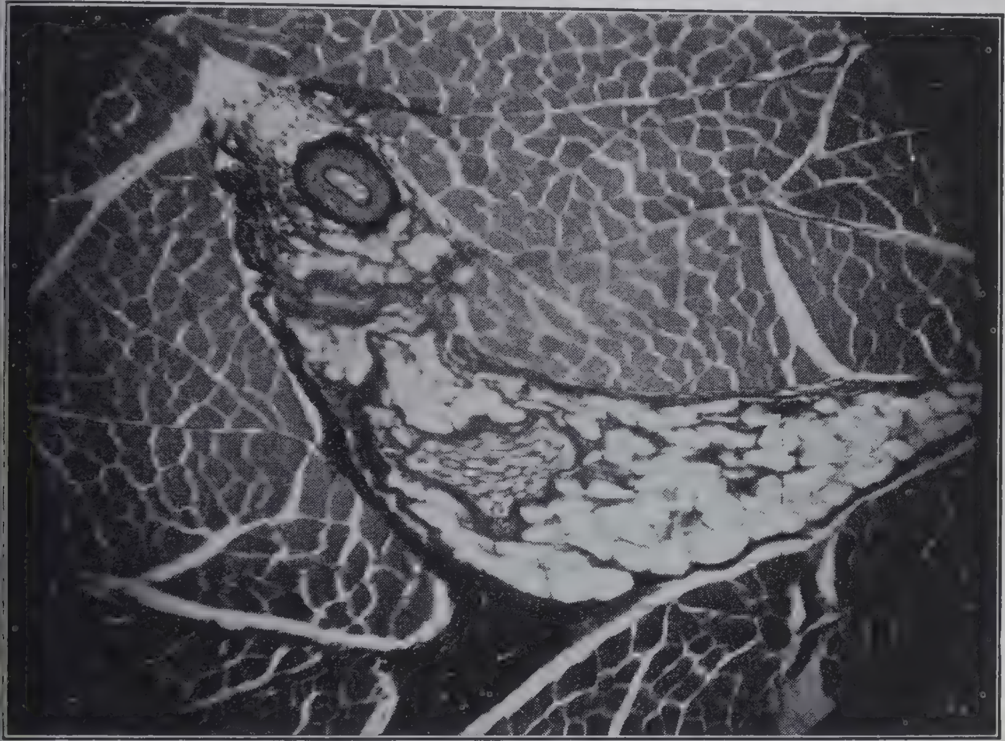


FIG. 26. A cross section of beef muscle, showing the fasciculi, connective tissue, and fat cells. The dense, somewhat triangular-shaped tissue is collagen interspersed with elastic fibers. The connective tissue around the empty fat cells (light ovals) varies in denseness. A cross section of one blood vessel is shown. Magnification approximately x 100.

Fat content of meat. The amount of subcutaneous fat in specific areas varies with the species (10). Hammond also found that the fat content of the longissimus dorsi of the pig increased from about 2% at birth to 5% at 28 weeks of age. The amount of fat in a particular muscle may also vary in different locations of the same muscle. Thus the longissimus dorsi muscle (10) of a 2-month old pig contained 8% fat near the head end and 2% near the tail end.

The average fat content of the interior of 5 muscles from 8 beef carcasses (animals varied in age from 6 to 48 months, with 6 of Commercial and 2 of Choice grade, old system) was determined in the author's laboratory. The average fat content for the 8 animals of the psoas major, anterior end of the longissimus dorsi, posterior end of the longissimus dorsi, the biceps femoris, semitendinosus, and semimembranosus muscles was 19.8, 14.6, 15.2, 13.8, 12.9, and 10.7%, respectively.

The addition of fat to the muscle increases its palatability. This is attested to by those who have scored meat from animals on a sublevel of nutrition. It is generally conceded that the presence of fat around and within the muscle increases the juiciness of the cooked meat. Both the water and fat of the adipose tissue contribute to this, the fat becoming softened during cooking. However, to secure marbled muscular tissues a rather thick fat covering beneath the skin is essential. Because meat is eaten primarily for its lean content, many homemakers think this fat covering is unnecessary. The fat covering can become so thick that it does not increase the palatability of the meat and is wasteful.

Color of fat. The color of the fatty tissue varies with the species, with different breeds of the same species, the age of the animal, and the feed. Mutton and pork have little color in the fat tissue. The yellow coloring matter of beef fat is carotene. Hence, the color is deeper when the carotene content of the feed is high. Fat of older animals is yellower than that of younger ones under the same feeding conditions. Fat of dairy breeds has a deeper yellow color than the fat of the beef types of cattle.

Firmness of the fat. Hilditch (11) has reviewed the literature on the fatty acid composition of depot fats of cattle, sheep, and pigs. The fat of cattle and sheep is fairly constant in composition. The fat of both these species contains a high proportion of saturated fatty acids. The fat from beef and mutton is much firmer than that of pork and poultry. Pork and poultry fat contain high proportions of unsaturated fatty acids.

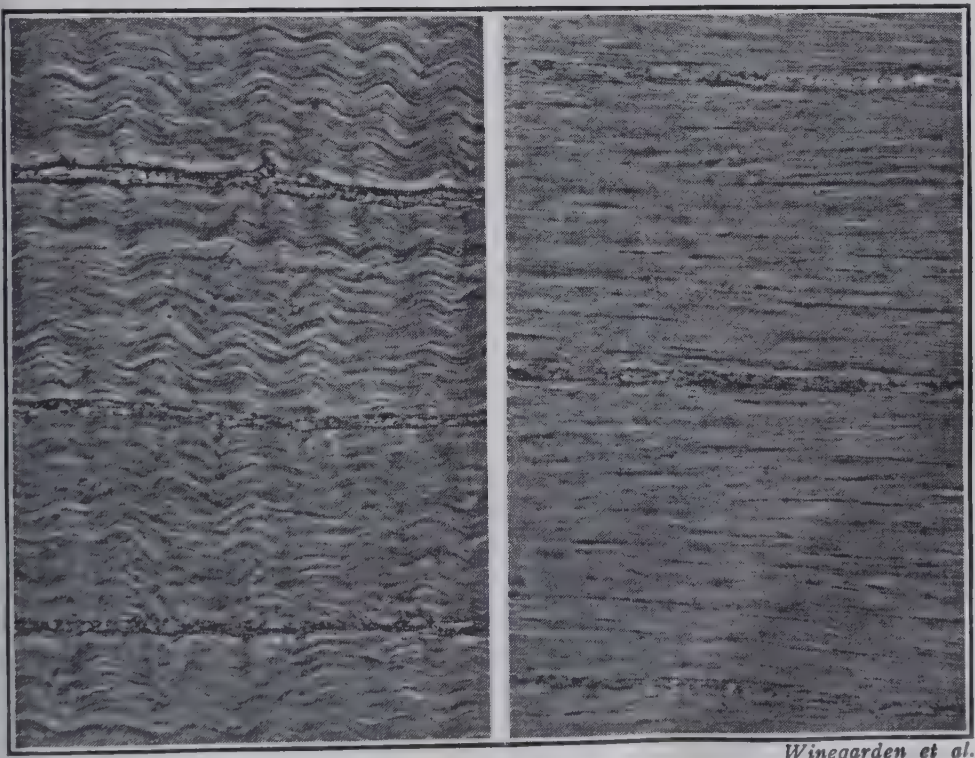
The firmness of pork fatty tissue varies with the location in the body from which it is obtained. The internal fat (that around the kidney) of pigs has the highest proportion of saturated fatty acids, and hence is the firmest of the depot fats from a given carcass. The firmness of the fat gradually decreases from the internal to the subcutaneous layer of fat. The depot fat of the pig is readily altered by the feed. Feeds, like soybeans or peanuts, with high proportions of unsaturated fatty acids produce very soft body fat. Bacon and hams from such carcasses are soft and oily to handle and cook.

Cruickshank (8) found that the depot fat of chicken, unlike that of the pig, is similar throughout the body of a given bird, but may vary widely from bird to bird. Chicken depot fat can also be altered by the type of fat in the diet.

Connective Tissue

Connective tissue is characterized by a small number of cells and much intercellular substance. It has many variations and transitional forms. This has been emphasized by electron microscopic studies (23, 24, 29). Some connective tissue is loose like that between organs; some is compact like that in tendon; some is dense like that in cartilage; and some fulfills specific functions. All of these connective tissues (12) are composed of a homogeneous matrix or ground substance. This ground substance has no visible structure. Fibers run through it. The extent and organization of these fibers, at least in part, differentiates the various types of connective tissue. The ground substance can be stained with toluidine blue. Angevine (12) states that as age progresses there is less ground substance present, the collagen fibers becoming more compact. This may explain why muscles from younger animals are usually more tender than those from older ones, for differences in connective tissue content of a given muscle are not always found in animals of different ages (21). Angevine reports that the connective tissue content of human heart muscle, in a study in his laboratory by Harman, was the same for all ages, infants through 80 years.

Collagen fibers. Of the collagenous fibers Maximow and Bloom (18) state that they "run in all directions and their ends cannot be found." The collagenous fibers often occur in bundles in some tissues. A group of wavy collagenous fibers is shown in Fig. 27. Each fiber is composed of fibrils, which impart a longitudinal striation. The fibers vary from 1 to



Winegarden et al.

FIG. 27. Beef connective tissue from a sheet in the flank region. See original article for source. At left, a bundle of unheated collagen fibers; at right a portion of the same tissue after heating 64 minutes at 95°C. Note that the heated collagen fibers have lost their waviness and appear as if stuck together. The small black lines between and within bundles are differentially stained elastic fibers. Magnification x 165.

12 μ in thickness; the fibrils, of course, are smaller. Collagenous fibers are colorless and birefringent. Their function is to bind and support other tissues. When arranged in wavy rows, the fibers can be stretched until the waves are straightened, so they have flexibility but are not elastic. Tendons are composed chiefly of collagenous fibers. As the tissue appears white in large masses it is often called white connective tissue.

Elastic fibers. The elastic fibers are thinner than the collagenous ones. Being highly refractive they appear very brilliant when observed microscopically. They branch readily and stretch like a fish net. The ends of single fibers often appear curved, resembling a shepherd's crook. The fibers are extremely elastic and hence function when both elasticity and strength are required. Ligaments are composed chiefly of elastic tissue, the fibers being arranged parallel and bound together by collagenous fibers. When massed together, as in ligaments, the color is yellow—hence the name yellow connective tissue. The uncooked ligamentum nuchae, the yellow ligament along the neck and backbone, can be used to show the elasticity of yellow tissue, as it will stretch when pulled.

Composition of connective tissue. The percentage of water in the connective tissue of the young animal is higher than in the older animal. The white connective tissue of the calf, according to Burger and Gies (15), contains about 68% of water, whereas that of the ox has about 63%. The water, collagen, and elastin content of the Achilles tendon (15) is 62.9, 31.6, and 1.6%, respectively, whereas that of the ligamentum nuchae (26) in the same order is 57.6, 7.2, and 31.7%. The following composition was found for the connective tissues used by Winegarden et al. (27).

TISSUE	MOISTURE %	TOTAL N % dry wt.	COLLAGEN N % total N	ELASTIN N % total N
Deep flexor tendon	66.5	16.8	35.5	0.007
Ligamentum nuchae	64.7	12.9	16.1	81.9
Aponeurotic sheet (flank)				
External portion	63.8	15.0	17.7	50.5
Internal portion	63.4	14.2	29.2	2.8
Fused portion	58.9	12.3	44.9	13.2

Effect of heat on connective tissue. Collagen is converted to gelatin by heat in the presence of water, and meat always contains water. The rate of conversion is affected by the temperature reached, the *p*H of the solution, the size of the pieces, and the denseness or kind of collagen. Thus the thickness of the connective tissue affects the rate of conversion of collagen to simpler products. See the chapter on gelatin for other factors affecting the conversion of collagen to gelatin.

Connective tissue when heated in air may soften for a short period and then become parchment-like. When heated in water it softens. Winegarden et al. (27) heated connective tissue strips in a thermostated waterbath. These strips were heated 1, 2, 4, 16, and 64 minutes at each temerature setting. Strips from the external portion of the aponeurotic sheet nd the ligamentum nuchae were heated at 5° intervals from 60° to 95°C. The connective tissue strips softened (as shown by pounds for shearing, ig. 28), lost weight, shortened in length, decreased in width, and in-

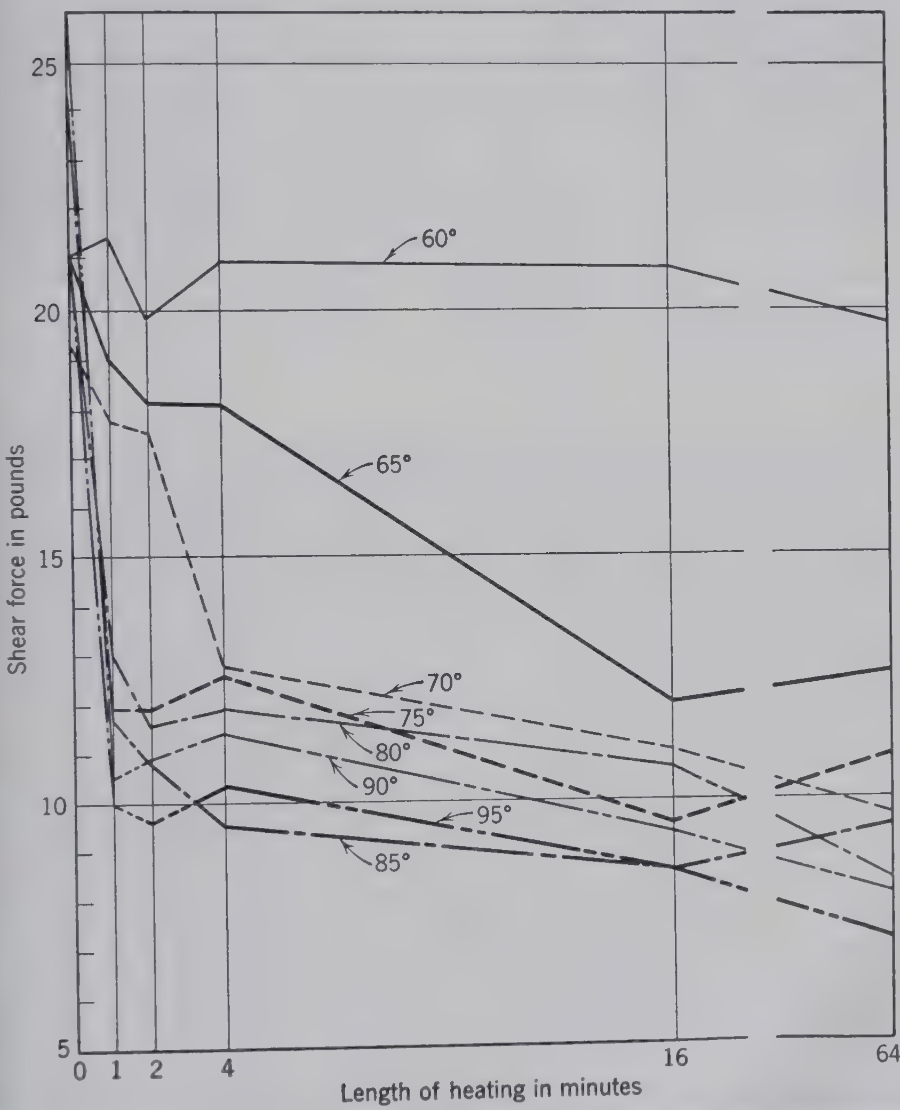


FIG. 28. Effect of heating connective tissue strips at various temperatures in vater for varying periods of time (27).

reased in thickness during heating. These changes occurred together, and, n general, the degree of change was greater as both time and temperature f heating were increased. The collagen content of the tissues also affected he extent of changes during heating, the changes being greatest with the issue containing the most collagen (deep flexor tendon) and least in the issue containing the most elastin (ligamentum nuchae). The collagenous tissues lost most of their weight within the first 2 minutes of heating. However, those with the most collagen tended to absorb water and regain weight with the 64-minute heating period. They also became sticky and gelatinous with the longest heating period at 95°C. Tissues from a calf 6 months old were less tough than those from an animal 42–48 months old. Animal variation, however, was great.

Microscopically, the collagenous tissue heated at 95°C for 64 minutes differed from that of the uncooked tissue, Fig. 27. The heated collagenous fibers lost their waviness, became straight, and appeared as if fused or stuck together.

It has been considered that little softening occurred in elastic tissue during heating. This study indicates that elastin is softened similarly to collagen but not to the same extent. If microscopic changes were brought about by heating the ligamentum fibers they were not noticeable at the magnifications employed. They did feel dry and dehydrated after heating.

Since it is difficult to isolate connective tissue within the muscle, it is easier to study the behavior of connective tissues in tendons and ligaments, then apply the findings to the behavior of the connective tissue within the muscle. The collagenous tissue is found in larger amount than the elastic tissue in any given muscle, although the amount of each tissue varies in different muscles. For example, the breast muscles of chicken and turkey and the tenderloin muscle of beef, lamb, and pork have a small amount of collagen and very little elastin. The semitendinosus muscle is characterized by having considerable elastin. In addition to the connective tissue around the fibers, the fasciculi, and around the muscle, there are areas of intercolated tendonous portions within the muscle. These microscopic tendonous areas are found more frequently in the less tender than in the tender muscles. Only three or four of these areas, and they were small in size, were found in the sections of the psoas major muscle. These intercolated tendons are small, of various shapes, and are affected by heat in a manner similar to the collagen tissue in the study by Winegarden et al. (27). The collagenous fibers of these small tendonous areas, upon heating to 70°C or higher, straightened and appeared fused together. See Fig. 29.

Granular tissue. Studies in this laboratory on roasts and braised cuts from eight animals of varying ages indicate that connnective tissue in muscle, to judge from its behavior in response to heating, may be divided into two groups, (*a*) a less dense tissue containing varying amounts of ground substance and (*b*) a more dense tissue with fibers definitely organized in bundles. See Figs. 29 and 30.

The less dense connective tissue is found around the fibers, in some areas around the fasciculi, and intermingled in the more dense tissue of the intercolated tendonous portions. The granular tissue was found in all microscopic sections prepared from roasts and braised cuts cooked to interior temperatures of 70°C as well as those cooked to 90°C, but not in sections from the raw muscles. The amount of granular tissue was greatest

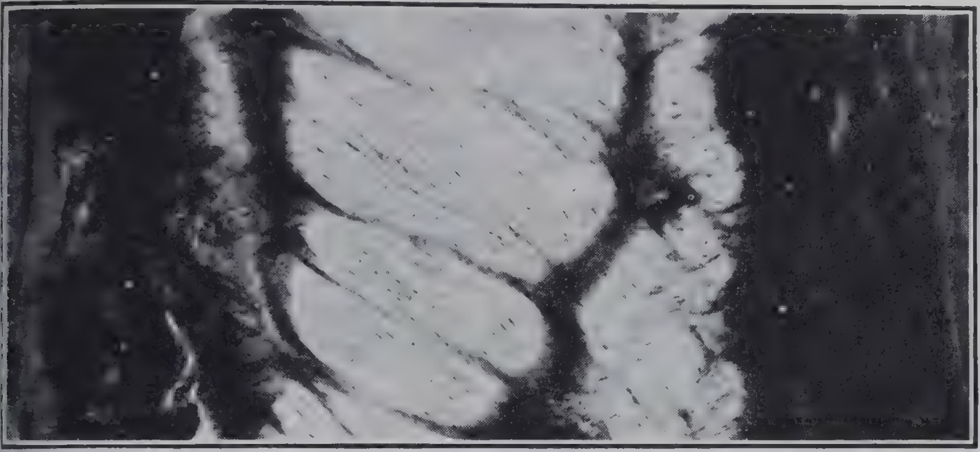


FIG. 29. In center, fused fibers of the intercolated tendinous portions from ooked semitendinosus of beef animal 6 months old. The granular tissue appears lack in the photograph. Muscle fibers at outer edges. Magnification x 150.

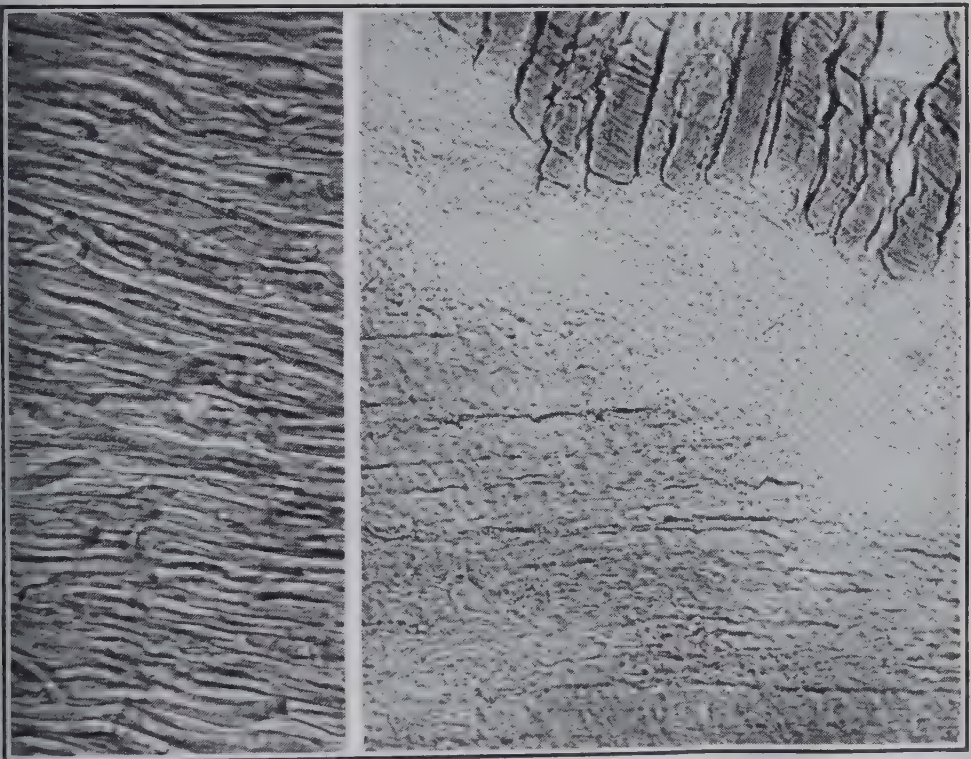


FIG. 30. *Left:* elastic fibers from the ligamentum nuchae after heating at 95°C or 64 minutes. They were not appreciably changed by heating. Magnification 165. *Right:* an intercolated tendinous area in the uncooked muscle at bottom of hotograph. In the middle the ground substance or matrix, which is altered by eating and probably is the source of the granular tissue. At top some muscle bers. Magnification x 100.

in sections from the muscles containing the most connective tissue. The principal source of the granular tissue appears to be the less dense connective tissue. Presumably the granular tissue is collagen that has been partially or wholly converted to gelatin. The bundles of wavy collagen fibers of the intercolated tendonous areas remained intact, behaving in the same way as the collagen fibers studied by Winegarden et al. (27); *i.e.,* they shortened, lost their waviness, and appeared as if fused together. See Figs. 28 and 29.

When sufficient connective tissue has been converted to gelatin during the cooking of meat, the fluid escaping when the meat is cut or the water in which the meat is cooked sets to a gel.

Connective tissue in fish. Experiments on thirteen species of fish (25) indicate that the content of connective tissue is greater in flesh from the tail and red meat than in flesh near the head and in white meat. No significant relationship was found between the toughness and connective tissue content of muscle. The ratio of collagen to elastin was lower in fish than in animal muscle.

Determination of connective tissues. There are several methods for determining the connective tissue content of muscle (14, 16, 17, 20, 22).

Connective tissue and grade. Mitchell and coworkers (20, 21) determined the moisture, fat, total nitrogen, collagen nitrogen, and elastin nitrogen content of various muscles in animals. In general, they found larger percentages of connective tissue in the less tender than in the tender cuts, though variation occurred. These workers also determined these same constituents in the longissimus dorsi muscle (ribeye) of ribs 9–11 from 12 beeves of different grades and ages. The elastin content of this muscle was small when compared to the collagen content. They found no relation between the ordinary market grading of beef and the connective tissue content. For example, the collagen nitrogen in per cent of total nitrogen was least in the longissimus dorsi muscle, 4.6%, from a 14–15-year-old cow of Canner grade and greatest, 9.4%, in a 2-year-old Choice steer. No organoleptic evaluation or pounds to shear samples were made in connection with the chemical determinations.

The Muscle Fibers

Each fiber is elongated, cylindrical, and multi-nucleated, the nuclei being elliptical in shape. The length of the fiber varies from 1 to 41 mm, the diameter from 10 to 100 μ, according to the muscle and the species of animal (18, 31). The fibers increase both in length and diameter during growth. Hammond (9) states that the average length of goat fibers is said to be greater than those of beef, and those of beef greater than those of mutton. Hammond (9) found that the average diameter of fibers in a particular muscle of Suffolk ram at birth, at 5 months, and at 4 years was 12.8, 40.3, and 54.1 μ, respectively. It is commonly accepted that the number of fibers does not increase after birth.

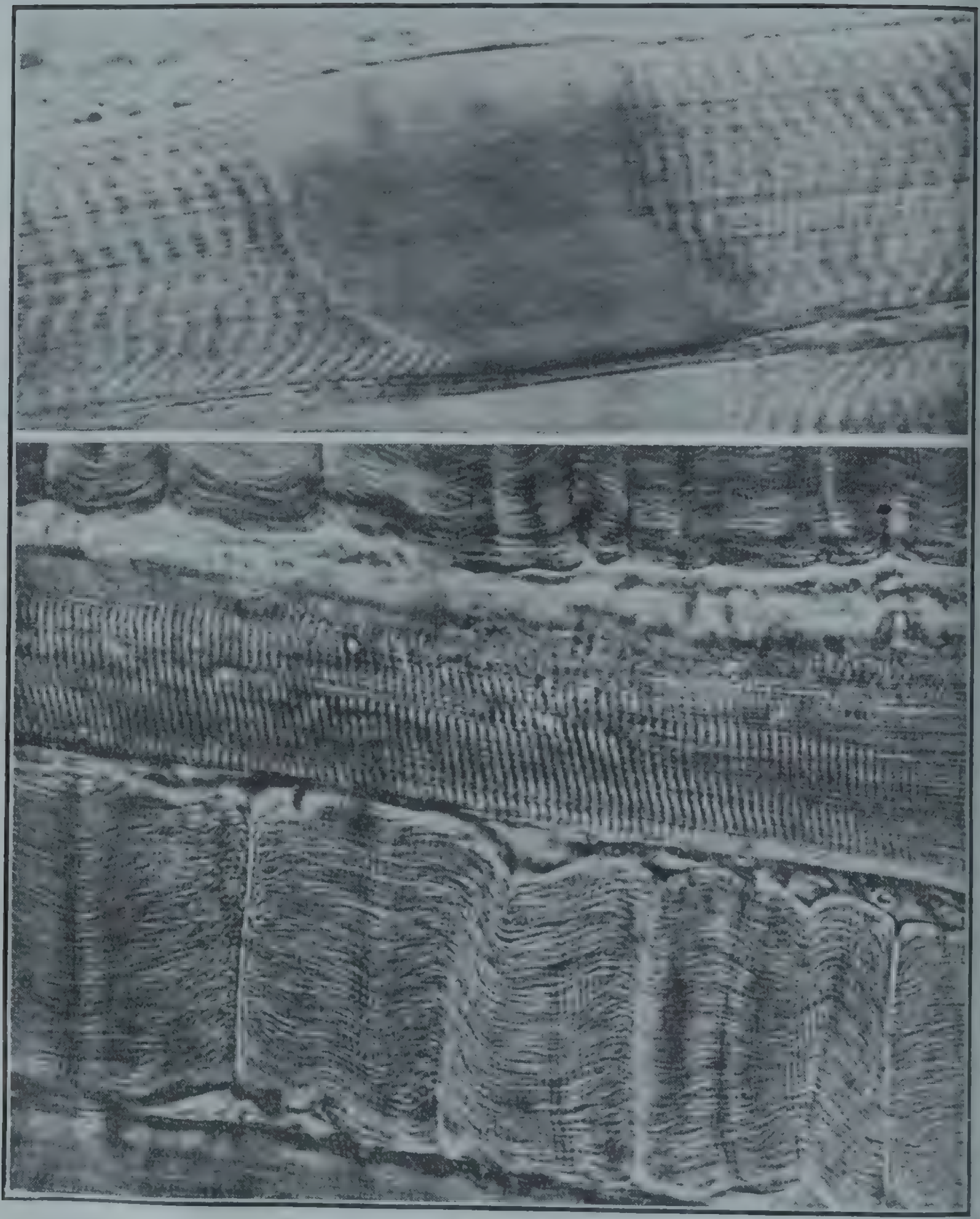
Each fiber is enclosed in the sarcolemma, a thin, colorless, elastic membrane about 1 μ thick. Each fiber contains fibrils or myofibrils, the diameter of which may reach 2 μ, which run longitudinally. These fibrils are composed of alternate dark (known as A or Q) and light (I or J) bands, which give the appearance of cross striations. The appearance of these cross striations, as well as the longitudinal ones, differs, depending on whether the muscle is at rest, contracted, or stretched. Carey (36, 37) has shown that under certain conditions the Z bands (a narrow dark band through light I band) are present whereas under others they are absent; and that Z bands are more constant in some muscles than in others. The fibrils are the contracting tissue. Between the fibrils is the sarcoplasm, the interfibrillar substance. The relative amount of sarcoplasm varies in different muscles, red ones having a larger proportion than white. Red muscles, according to Maximow and Bloom (18), usually contain more fat granules than white ones and are more "muddy" in appearance.

The longitudinal striations are directly or indirectly related to the tenderness of the muscle. The longitudinal striations are more distinct with the ordinary microscope if obtained from the muscle soon after death. There is a tendency for the longitudinal striations to become less distinct and to disappear as the muscle is aged. The muscle becomes more tender with aging. Perry and Horne (40) in an electron microscopic study found that the bands (cross striations) retain their structure more readily in muscle in which rigor has developed. They suggest this may be due to the mild fixative action of the lactic acid produced during the onset of rigor.

The predominance of the longitudinal striations in freshly excised sections from different muscles of beef and chicken varies considerably. Whether the cross or longitudinal striations are predominant depends upon the particular muscle being examined, and possibly upon the animal. One fiber, Fig. 31, may have predominant longitudinal striations whereas the adjoining one may have predominant cross striae. All the predominant striae in one area may be cross ones, in another longitudinal. The tenderloin muscle is always tender, even before aging. Only cross striations have been observed in this muscle in this laboratory. As the semitendinosus muscle is aged there is a trend for only the cross striae to be visible. In other muscles, such as the longissimus dorsi, biceps femoris, and the semimembranosus, some longitudinal striae may persist after the cut is aged, but they are far less numerous than in the fresh tissue.

For those interested, several excellent electron microscopy studies of muscle have been reported (30, 43, 44, 45).

Effect of exercise upon fibers. Few studies have been published concerning the effect of exercise upon muscle fibers. Beard (33) states that, whereas the "muscles which are brought most into activity and those performing the greatest amount of work may not possess a larger fiber than those muscles which are less active, the more active muscles do have



Lowe and Academic Press

FIG. 31. *Upper:* rigor node from pectoralis secundus of thigh of roaster; agec 30 minutes. Magnification x 625. *Lower:* fibers of longissimus dorsi of beef agec 24 hours. Note in one fiber that both the cross and longitudinal striae are prominent, whereas the longitudinal striae predominate in the wavy fibers. Magnifi cation x 450.

a thicker perimysium and apparently more substance in the fiber, as manifested in the staining characters of the sections."

Constituents of Muscles

Of the many constituents of muscles, some are (*a*) water, (*b*) inorganic and organic salts, (*c*) pigments, (*d*) non-nitrogenous extractives (lactic acid, etc.), (*e*) nitrogenous extractives (creatine, urea, etc.), (*f*) carbohydrates, (*g*) fat, (*h*) enzymes, (*i*) proteins, and (*j*) vitamins. Some of these constituents are present in large, some in small amounts. Some are more concentrated in the fluids, others in the fibers.

Water. Muscle contains a large proportion of water. The water content of the fresh tissue varies somewhat, being smaller as the fat content increases. Callow (7) found that the water content of the psoas muscle, determined immediately after death and calculated on a fat-free basis, was the same for cattle, sheep, and hogs, the average being 78%.

Inorganic salts. Some elements like phosphorus are present in both organic and inorganic combinations in muscle. The salts in meat are present in a complex equilibrium. It is known that potassium is more concentrated in the fibers than in the fluids, whereas sodium is more concentrated in the fluids. The NaCl content of the fluids is about 0.85%. Concentrations of these salts, as in drippings from roasts, give a salty flavor. It is possible that the salts have some role in the tenderness of meat, just as the salts of milk affect its heating. The role of salts in the tenderness of meat has not been investigated to any extent.

Muscle pigments. Myoglobin is the chief pigment producing the pink to red color in muscle, although some red corpuscles with their hemoglobin remain in the capillaries when the blood is drained from the animal at time of slaughter. The depth of color of the muscle depends upon the concentration of the myoglobin. The myoglobin is also darker at a higher *p*H; hence the color of the muscle brightens with the post-mortem drop in *p*H. The amount of myoglobin in muscle varies (*a*) with the age of the animal (61, 67), (*b*) with the breed (dairy cattle have darker-colored muscles than the beef types), (*c*) in different muscles in the same animal (pork, poultry, rabbit), and (*d*) with the extent the muscle is exercised. Lawrie (61) found that the concentration of myoglobin increases rapidly from birth, becoming fairly constant after the animal has reached a definite age (2 years in the horse and 1 in the pig). Of the various factors, exercise has the greatest influence on the myoglobin concentration. Whipple (67) found nearly twice as much myoglobin in the muscles of hunting dogs as in those of household pets. Lawrie (61) found muscles of hunters and racers had more myoglobin than those of draft horses. The greatest contrast in Lawrie's figures was for the breast muscle of hens and pigeons, about 0.006 and 0.249% by weight, respectively, or over 40 times as much myoglobin in pigeon as hen's breast muscle. Anemia reduces the amount of myoglobin (68). This applies to milk-fed poultry and veal.

The properties of myoglobin and hemoglobin are very similar, although they differ in molecular weight, spectral absorption, and affinity for CO (55). Both have about the same amount of iron, 0.34% (55, 69), and their color reactions are similar. The color reactions of myoglobin are of interest in the self-service merchandising of packaged meats (57, 62, 66) and in cooking meat. Muscle is a darker color when first cut but becomes a brighter red after exposure to the air. The oxygen of the air combines with myoglobin to produce oxymyoglobin. The bright red color of oxymyoglobin is acceptable to the consumer. The brightening continues until an optimum is reached, usually in about 30 minutes. With continued exposure, the muscle surface begins to dehydrate and the color darkens. A high temperature hastens the darkening. Certain kinds of light (57, 62, 69) act as catalysts to color changes in cured and table-ready meats. This influences maintenance of acceptable colors of meat in refrigerated show cases and in transparent wrappings. Slow oxidation of the oxymyoglobin produces the brown metmyoglobin. This brown color usually develops first at the edges of the meat. Its formation is hastened by the presence of salt (54). Green discolorations (60) are caused by the action of certain bacteria on the muscle pigment. The product is not toxic.

Effect of heat and aging. Myoglobin and hemoglobin are unstable to heat. Hence, when fresh meat is cooked to a high enough temperature decomposition products are formed. The globulin part of the molecule coagulates, and the hematin produces the brown or gray color of well-done meat. Dilute acid and alkalies may also decompose the myoglobin. The red color of cured meats (ham, etc.) is retained during cooking for the nitroso-myoglobin compound formed during curing is heat stable. The temperature at which decomposition of the myoglobin starts appears to be around 65–70°C, although this may be influenced by the rate of heating and other factors. Beef roasts that have been aged 40–60 days develop the dark color of well-done meat at much lower temperatures than do roasts from the same animal cooked under the same conditions, but aged 10–20 days.

Dark cutting beef. This is beef that does not become bright red when cut and ranges from brownish to very deep blackish red. Because of th abnormal appearance it is suspected by the purchaser as not being acceptable The possible causes of the dark color are discussed by Hall et al. (59).

Non-nitrogenous extractives. Lactic acid is always present i muscle tissue. The amount is small while the muscle is at rest and increases during and after exercise. After death the percentage of lacti acid in the muscle increases.

Nitrogenous extractives. Muscle tissue contains end products o protein metabolism. As these accumulate during life, they are remove from the tissues by the body fluids and are excreted through the kidneys Creatine and creatinine are found in the muscles and to a lesser extent i the blood. Uric acid and other nitrogenous extractives are also found i e muscles. It was considered at one time that the nitrogenous extractives ere responsible for the flavor of meat. Flavor of meat is now considered come from other constituents of the muscle.

Enzymes. Proteolytic enzymes in meat are of interest because of their ssible role in increasing the tenderness of meat during aging. Cathepsin present in both animal cells and unicellular organisms. Its probable role 53) in the living cell is in the synthesis of proteins. But little cathepsin 58) is found in tendons, the greater quantity being present in muscle.

Snoke and Neurath (65) isolated extracts of high proteolytic cathepsin ctivity from rabbit muscle. This cathepsin is reported to have maximum ability at *p*H 6.0 and optimum activity at *p*H 4.0. Ferrous ions cause n increase in its activity, whereas magnesium and manganese have less ffect.

Carbohydrates and fat. The carbohydrate found in muscle tissue is lycogen; that in the blood is glucose.

The distribution of the neutral fat has been considered. Each cell has fairly constant content of lipids.

The proteins of muscle. The proteins of the muscles are composed argely of two types: (*a*) the structural or extracellular proteins, which onsist principally of collagen and elastin; and (*b*) the intracellular or rotoplasmic proteins. The structural proteins are characterized by their nsolubility in salt solutions. In contrast, the intracellular or protoplasmic roteins are soluble in certain concentrations of salt solutions such as LiCl, NaCl, KCl, NH_4Cl, Na_2SO_4, $MgSO_4$, $(NH_4)_2SO_4$, and Na_2HPO_4. Because of this they are often referred to as the soluble proteins. However, the percentage of these proteins soluble in the different salt solutions, even at the same concentration, varies (46). Denaturation of the proteins, whether by freezing or other means, lessens the amount soluble (35).

Nomenclature of the proteins. The nomenclature of the muscle proteins has changed considerably during the last decade. New proteins have been isolated and others have been shown to have more than one component. Myosin, myogen, globulin X, and myoalbumin (46) had been considered the principal soluble proteins. Tropomyosin (32) was added to this list. The old myosin is now known to be composed of two proteins to which have been given the names myosin and actin (50). Neither myosin or actin, alone, brings about contraction. When combined in the right proportions to form actomyosin, they have the property of contractility. Several studies on the characteristics of actin, the new myosin, and actomyosin have been published (30, 38, 44, 47, 48, 49, 52). Szent-Gygöryi (51) states that the most interesting property of actin is its ability to exist in both globular (G-actin) and fibrous (F-actin) form. The reversible reaction from fibrous to globular and back again occurs during each contraction. Szent-Györgyi (52) states that the new myosin is also a complex structure and should be called a system rather than a substance. Myosin has enzyme activity, being a phosphatase (56), which splits a phosphoric acid group from ATP (adenosine triphosphate). Myosin (52) can be pictured as an inactive skeleton to which are attached a number of globular proteins. Without these globular proteins myosin is inactive. These globular proteins have been given the name protins to distinguish them from the other muscle proteins.

Bosch (34), in a quantitative electrophoretic study of the muscle proteins soluble in dilute salt solutions, found 9 protein components. Not all these proteins were identified with the known isolated ones.

Isoelectric point of intracellular proteins. Smith (46) reports the isoelectric point as follows: myogen, *p*H 6.5 to 6.7; myoalbumin, *p*H 3.0 to 3.5; the old myosin, *p*H 5.5; and globulin X, *p*H 5.2. He states that the low values (4.5 to 5.0) previously reported for myogen are caused by admixture of this protein with myoalbumin. Szent-Györgyi (51) gives the isolelectric point of the new myosin as *p*H 5.2, of actin as *p*H 4.7.

Coagulation of meat proteins. The protoplasmic proteins are coagulated by heat. The literature indicates no unanimity of opinion concerning the coagulation temperature of the various intracellular proteins. Some denaturation probably occurs at 60°C or below, for the firmness of meat cooked to these interior temperatures is altered from that of raw meat. Coagulation of proteins is an endothermic process. When meat is cooked at low oven temperatures (80–120°C), the interior temperature rise of the meat is often stationary for several minutes between 75° and 80°C. This may indicate that considerable coagulation is taking place at this temperature range. The characteristics of the cooked meat, *i.e.,* rare, medium well-done, or very well-done, are dependent largely upon the degree of coagulation of the intracellular proteins.

Coagulation is affected by many factors. The factors affecting coagulation are discussed in more detail in Chapter 1 and under egg cookery Among them are the concentration of the protein, the electrolytes and nonelectrolytes present, the time held at a given temperature, and the temperature reached. Coagulation is accelerated by a rise in temperature.

Post Mortem Changes in Meat

After slaughter, changes occur in the skeletal muscles of animals. Thes changes are brought about by enzymes, by chemical and physical mean which alter the structure and the chemical composition, and by microorganisms.

The fat becomes firmer as the meat cools.

Muscle in the living animal is (*a*) pliant, soft, gel-like, yet somewha viscous. After slaughter the muscles pass from this state into a stiff o rigid one (*b*) known as rigor mortis, or muscle rigor. After some tim the muscles again become pliant. This stage (*c*) is known as the passing o rigor. With longer storage enzymes and chemical changes produce th changes (*d*) of ripened meat. With bacterial action and still greate changes (*e*) incipient putrefaction occurs. The passage from one stage t ie next is gradual with no definite dividing zone. But certain changes in ie muscle occur simultaneously. These include shortening and hardening f the muscle, increase in heat production for a period after death, lowering f the glycogen content, increase in lactic acid and consequent lowering f pH, increase in soluble inorganic phosphate, decrease in ATP, lowering f resistance to electric current, changes in elasticity, and changes in the icroscopic appearance of the fibers.

Development of rigor. There are two current theories regarding the evelopment of rigor mortis: one by Szent-Györgyi (50), the other by ate-Smith (70). ATP is involved in both theories. Bate-Smith states, The stiffening of muscle and the decreased extractability of the proteins i rigor run parallel with the disappearance of ATP from the muscle."

The speed with which rigor develops may be affected by many factors, ome chemical, some physical. The following have some influence: the pecies, the age of the animal, activity or exercise before death, the temerature of holding the carcass, and possibly the scalding procedure used ith pork and poultry.

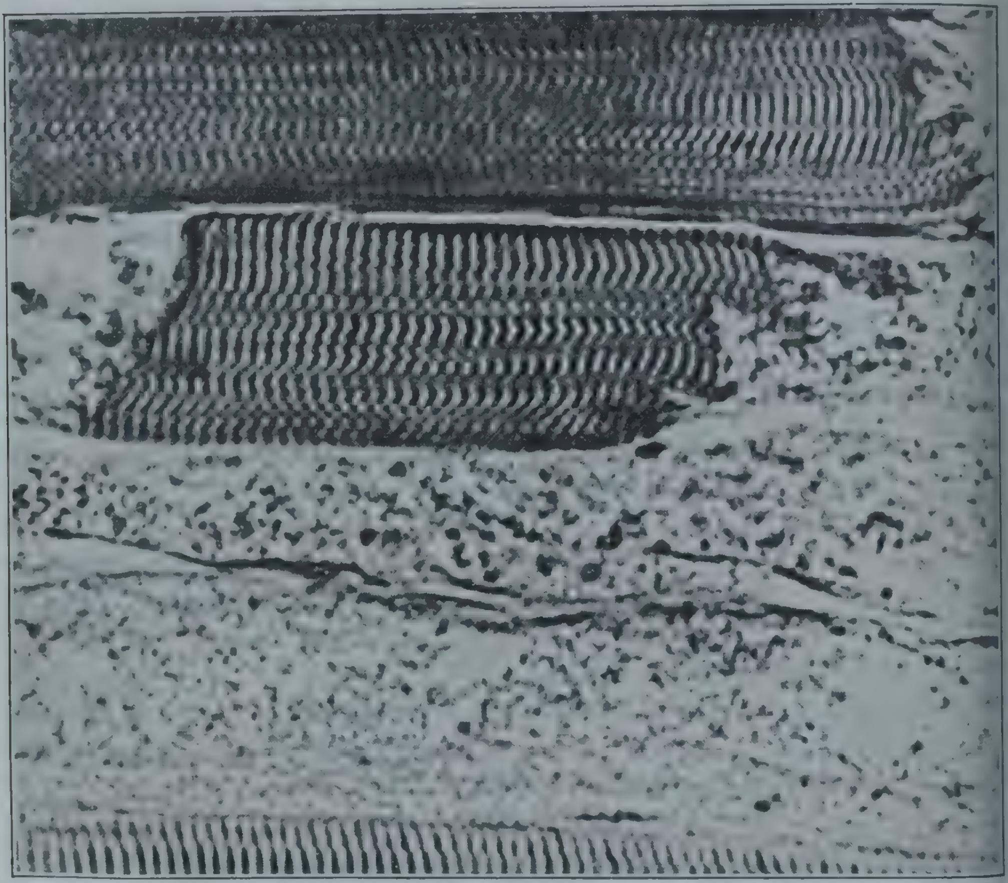
Smith (84) observed that onset of rigor is rapid in animals that struggle efore and after stunning, considerable lactic acid being developed by this ctivity. Benson (71) finds that rigor sets in more rapidly in fatigued sh (trawl caught) than in the muscle of fish taken from a pen. It would eem that onset of rigor in animals chased before killing in hunting would e rapid and that the flesh would not keep so well as that from animals illed without activity prior to death.

Steiner (86) states that rigor sets in more rapidly in young than in old nimals. In the author's laboratory it was found that onset and passing f rigor was more rapid in broilers (136) than in roasters (138), and in urn faster in roasters than in hens (143). Broilers had to be aged about hours before cooking was started for the breast muscles to receive a enderness score of 8, roasters about 6 hours, and hens 12 hours or longer. Thigh muscles tenderized far less rapidly than the breast muscles of poulry. Cooking, probably because of the high temperature, hastened the assing of rigor.

Ramsbottom and Strandine (82) state that rigor develops in 8–24 hours, ometimes earlier in beef carcasses, and may persist 24–72 hours. Roschen t al. (83) state in a patent application that aging is not effective in inreasing the tenderness of beef until after rigor mortis has developed. During the 16–24-hour period of rigor there is a toughening of the meat. Under these conditions 2–3 weeks' aging may be required to produce aceptable meat. However, if the carcass is placed immediately after laughter in a room at about 37°C and 90% humidity for 4–5 hours, rigor s complete at the end of this period. The carcass is then placed in a cooler t approximately 1°C. With this treatment the subsequent aging period s shortened.

Fibers in rigor. Rather distinct longitudinal striations, wavy and kinky fibers, and rigor nodes, Fig. 31, characterize the microscopic appearance of muscle in rigor. Carey has published excellent photomicrographs of the structure of frog's striated muscle in heat rigor. For the microscopic appearance of fibers during and after passing of rigor, see papers by Ramsbottom and Strandine (82) and Lowe (137).

Tenderness of muscle during and after the passing of rigor. Longitudinal striae become less distinct, and the fibers straighten with aging. Breaks appear at random points in scattered fibers. With further disintegration, which appears to be autolysis, the area of the breaks and their frequency increase. In uncooked fibers the cross striae disappear, in cooked ones they disappear or are changed to granular-appearing tissue. See Fig. 32. These changes are correlated with the tenderness of the muscle. The tenderness increases with aging of the muscle.



Hanson

Fig. 32. Photomicrograph of cooked fibers of breast muscle of chicken. The carcass was stored 118 hours before cooking. The change from the cross-striated structure to the grandular type is brought about by autolytic changes. The meat increases in tenderness with these changes. Magnification x 825.

Lehmann (78) was one of the first to measure the increase of tenderness f beef during aging. He used "skin" (flank) and loin muscles. Tenderess was determined by the force necessary to plunge iron teeth through mples of uniform size. Aging increased the tenderness.

Several studies have been made in the author's laboratory on the effect f aging on the tenderness of muscle, two with beef (76, 80) and four with oultry (136, 138, 143, 144). In these studies one of the outstanding haracteristics was the variation in tenderizing of the muscles from animal o animal; yet the average shear force or scores for a group of 5 or 10 birds f the same age and aging periods were usually similar. The tenderness cores and the average shear force for the breast muscle from the study on oasters is shown in Fig. 33. As described by Lehmann (78) the increase 1 tenderness was sometimes slower, sometimes quicker.

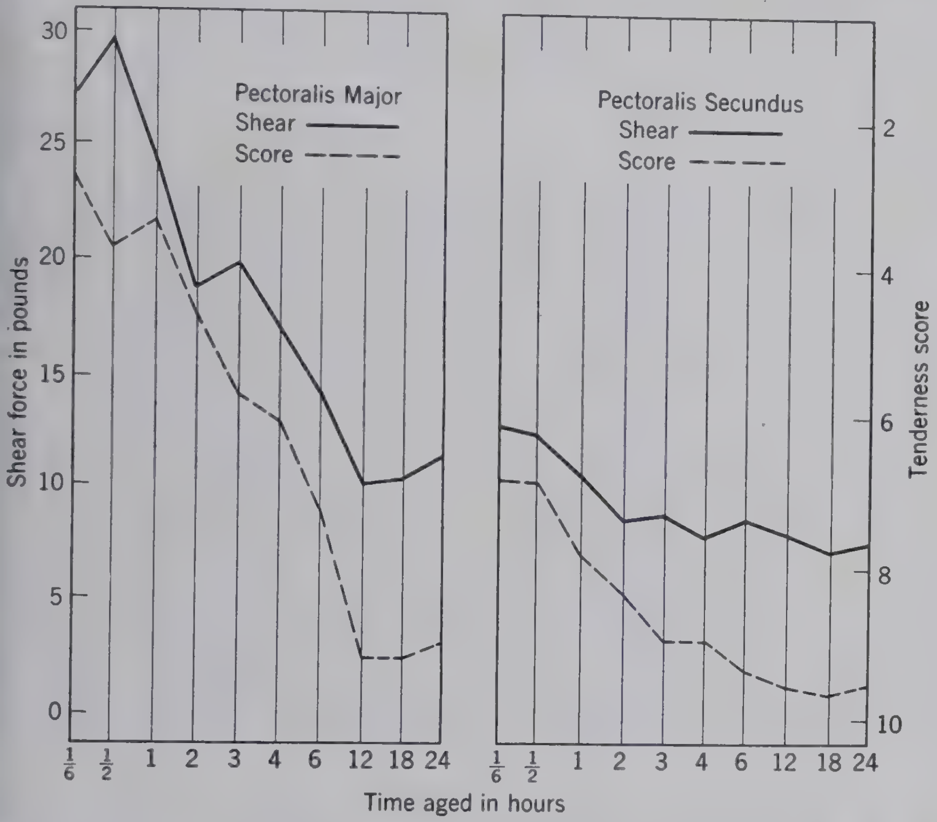


FIG. 33. Average tenderness scores and shear force (in pounds) of the two reast muscles of roasters aged varying periods of time before cooking. Each oint is average of 10 tests.

If rigor develops during cooking the muscles are extremely tough and he carcass of the bird is somewhat twisted and drawn or the muscles of eef cuts are drawn. Yet, if a cut of beef can be cooked so quickly that igor does not develop during cooking, the muscle is tenderer than if rigor as developed.

Ramsbottom and Strandine (82) cooked steaks in deep fat at 121°C to an interior temperature of 76.7°C. Steaks from the same animals were cooked after various aging periods from 2 hours to 12 days. Steaks cooked 2 hours after killing the animal were more tender (score 5.7) than those aged 11 hours (score 3.2) but less tender than those aged 12 days (score 8.5). Shear tests were in agreement with the tenderness scores, being 17.5, 19.2, and 14.5 pounds, respectively.

Paul et al. (81) confirmed the results of Ramsbottom et al. with steaks. They found that steaks were tender immediately after slaughter, became less tender with storage up to 24 hours, then increased in tenderness with longer storage. But roasts from the same animals, which required a longer time for cooking, were least tender immediately after slaughter and became increasingly tender as the cold-storage period was lengthened. Thus it was thought that the slow heat penetration during roasting developed rigor in the roasts cooked immediately after slaughter, whereas rapid heat penetration in the deep fat fried steaks coagulated the muscle substance before the short-time aged steaks could go into rigor.

Rate of fall in *p*H. The rate of acidification of muscle post mortem varies; Smith (84*e*) states that the outstanding feature of this change is the extraordinary variability from animal to animal and also from one small area to another in a particular muscle. This last variation becomes nil after the acidity of the muscle reaches *p*H 6.2. In some animals the latent period is long before the acidity increases; in others a rapid drop in *p*H occurs from the time the earliest observation can be made. A correlation between the length of the latent period and the activity of the animal before and after stunning was observed. Animals very active just before death have a rapid decrease in *p*H values of the tissues, whereas in animals killed when under the influence of certain anesthetics the initial *p*H is high and the latent period long.

***p*H and muscle characteristics.** The amount of lactic acid produced post mortem and hence the *p*H attained depend on the glycogen content of the tissues at death. With a greater glycogen reserve, more lactic acid is produced, and the *p*H is lower. The *p*H value of the intercellular fluids in living muscle is around 7.4; that in the interior of the fiber is said to be 6.9 or lower (74). The *p*H values of muscle during post mortem changes may reach 5.3 or lower, but values of 5.5 to 6.0 are common.

The development of greater acidity in the muscle imparts better keeping quality to the meat, as microorganisms do not grow so well in a more acid medium (35).

Open structure of muscle. Callow (35) states that shortly after death muscle has a close microstructure. With the development of lactic acid the microstructure becomes more and more open. Muscles from fatigued animals have less oxygen, less lactic acid, a higher *p*H, and a closer microstructure than muscles from well-rested animals. Resting an animal after fatigue yields muscle tissue with progressively lower *p*H. In addition, the psoas muscle of pork is more readily affected by fatigue than the longissimus dorsi. Thus fatigue before death may increase the differences among muscles in the carcass.

Callow (35) found that the change from a close to an open microstructure was slowed down by rapid cooling. The open microstructure appears to correspond to the histological change during aging. It also appears to be related to the observation of Roschen et al. (83) that holding a carcass at 37°C for 4–5 hours before cooling hastens the aging of the muscle.

Salt (35) penetrates ham and cuts used for curing more readily if an open structure has developed. Freezing (35) changes the structure to such an extent that any previous differences in structure because of rate of cooling or other factors are completely obscured.

Electrical resistance. Callow (72*a*, *b*, *d*) observed that the post mortem changes taking place in muscle are reflected in the resistance to the passage of an electric current through the muscle. This resistance is greater across than lengthwise of the fibers. As post mortem changes occur the resistance across the fibers becomes the same as that parallel to the fiber. The change from high to low resistance is accompanied by an open structure. Callow concludes that the membranes around the fibers are broken. Another characteristic of the open structure is that the surface of the meat feels wet.

Effect of massage. Callow (72*c*) found that massage of the psoas muscle of pork brings about a very rapid drop in electrical resistance, the reduction across the fibers often reaching half its initial value in 30 seconds. Gainer et al. (75) found massaging roasters aged 30 minutes before cooking did not increase the tenderness over those of the non-massaged control group. Aging 60 minutes before starting cooking did increase the tenderness significantly at the 1% level over those aged 30 minutes.

Changes in elasticity. Smith (85) found that the modulus of elasticity measured along the fibers increases about tenfold during post mortem changes. "The modulus of connective tissue, in the form of rat's tail tendon, is about 1000-fold that of freshly excised muscle. The connective tissue does not contribute to the stiffening which muscle undergoes in rigor."

Post mortem changes and heat penetration. Hanson et al. (136) found that the cooking time decreases significantly as the time between killing and cooking of broilers increased; in other words, heat penetrates the muscle more readily as post mortem changes progress. Alexander and Clark (120) have reported similar results with legs of lamb. This may be connected with the increased amount of juice, if extensive evaporation is prevented, that can be pressed from the muscle as aging progresses.

Palatability changes during aging of meat. Aging includes the entire storage period until the meat is consumed. The extent of the changes during storage depend on the length of storage and the storage temperature. Changes are very slow in frozen meat, more rapid in refrigerated cuts, and still more rapid at temperatures above those used for refrigeration. At a cooler temperature of 1–2°C, 10–20 days improves the tenderness of beef, and 20–40 days seems to impart the optimum flavor. To judge from scores of meat in the author's laboratory, 40–60 days usually gives too "high" a flavor for most persons. Since surface areas are proportionately greater in smaller pieces than in larger ones, surface changes, such as oxidation, will be greater in small cuts. It is doubtful if the increase in tenderness after 20–30 days' storage is enough to pay for the increased cost and trouble of storage.

Noticeable changes during aging are the increased tenderness, change in flavor, and increase in ease with which juice may be pressed from the meat. The term "ripened meat" is often used when the aging changes are rather extensive. It is difficult to find adjectives to describe the flavor of ripened meat. In addition to being tender and juicy, to the author it is more acid, richer, and somewhat high or game-like in flavor. The fat may have an oxidized flavor. Whether one prefers the flavor of ripened meat or that of very fresh meat is largely a matter of personal choice.

Hoagland et al. (77), in tests on beef stored just above its freezing point, agreed that the flavor and tenderness improved with 15–30 days of storage. With storage for 45 days and longer, they speak of an "old," "gamey," and "off" flavor. With longer storage than 56 days the flavor was not palatable, "old" and "off" being used to describe the changes in flavor. From the comments, apparently they preferred the meat from the animal stored 56 days to that stored 45 days. This illustrates the variability in the rate of post mortem changes in individual animals.

Roasts from ripened beef brown more readily—and this is true for both the fat and lean—than unripened roasts from the same animal cooked under the same conditions.

Finished carcasses are best for ripening. Well-finished carcasses are best suited for ripening, as they will not mold or become sticky so readily as those with little fat. The mold that may develop on the surface must be trimmed off before cooking.

Incipient putrefaction. Much discussion has occurred concerning the presence of bacteria within muscle. Moran (79) states that in freshly killed muscle there is usually a low bacterial count. Hoagland, McBryde, and Powick (77) found that certain bacteria normally present in some carcasses of beef possess no pathological significance and do not multiply in proper cold-storage conditions. At low storage temperatures, spoilage by bacteria is most prevalent at the surface of the meat. Bacterial growth is slow during rigor, for the acidity of the meat does not favor the development of microorganisms. But with longer storage of meat, the acidity of the meat is lessened, which favors bacterial growth. Growth of bacteria is indicated by the formation of slime or stickiness on the surface of the meat.

Enzymatic changes in meat during storage. During life the enzymes of meat are connected with the metabolic processes of the body. The proteolytic enzyme of meat, the cathepsin, may be a system instead of a single enzyme. Although practical experience and organoleptic and shear force tests bear out the assumption that autolysis occurs during the aging of meat, very little is known about the actual tenderizing process. Histological studies show changes in the muscle fibers with aging of the meat. Winegarden et al. (27) found only very slight increase in tenderness of the connective tissues aged 35 days as compared to those from the other side of the same animal aged 10 days. This suggests that the major portion of the autolysis may occur in the fibers rather than the connective tissue. Smorodintsev and Nikolaeva (64) state that the activity of cathepsin decreases in spite of the fact that the *p*H of meat is optimal for its action. Its activity (63) is reduced 40–45% in the first 24 hours of aging and an additional 25% during the next 5 days. The activity of trypsin increases during the first 24 hours, then drops sharply. On the other hand, they state that pepsin activity reaches 2.5 times its initial value after the first 10 days of aging.

Hoagland et al. (77) found that the increase in amino nitrogen amounted to 3–7% of the total nitrogen of the beef after 14–177 days of storage. This increase in amino nitrogen was thought to be due to enzyme action.

Enzymatic changes are usually brought about more rapidly at room temperature. At very low temperatures the action may be slow and unlike that at higher temperatures, owing to differences in activity of different enzymes at different temperatures.

The lipolytic enzymes may bring about hydrolysis of fatty tissue during storage. Oxidation of the fat is probably the major factor in bringing about flavor change in the fat. The oxidative changes are greater in the surface than in the interior fat. See Chapter 4 for discussion of the peroxide changes in exterior and interior fat during frozen storage.

Chemical changes. In storage of meat the changes due to different factors such as bacteria and enzymes are brought about simultaneously. The chemical changes are the changes in the percentage of the different constituents of the meat, however they may be brought about. Stored meat usually loses weight by moisture loss. Emmett and Grindley (73) found that beef refrigerated 22 days compared with meat from the same animal refrigerated 2 days at 0.5–1.7°C (33–35°F): (*a*) had lost no water; (*b*) the percentage of water-soluble solids, the soluble, insoluble, and total protein, the non-coagulable protein, the nitrogenous and total organic extractives, the forms of ash, the total nitrogen and the total phosphorus all remained practically unchanged; (*c*) the consistent real changes were a distinct increase in the total soluble and the soluble inorganic phosphorus, being 8.0 and 17.9%, respectively, and a decrease of 8.3% in the non-nitrogenous organic extractives; (*d*) the nutritive value of the meat was unaltered. After refrigeration for 43 days the chemical changes in the meat were greater in number than those for the 22-day sample. When allowance was made for the moisture loss they found a definite increase in the soluble dry substance, the nitrogenous, non-nitrogenous, and total organic extractives, the total soluble nitrogen, and the soluble inorganic phosphorus. There was a slight increase in the soluble coagulable and total soluble protein nitrogen and in the insoluble and total nitrogen.

They found the cooked meats from the 43-day-refrigerated sample higher in water content, therefore juicier, than the 6-day-refrigerated sample. From comparisons of other losses that occurred in the cooked 43-day sample they concluded that it was as nutritious as that from the cooked 6-day-refrigerated meat.

Changes Produced in Meat by Cooking

Meat is cooked to sterilize it and (for most persons) to increase its palatability. The changes brought about by cooking may be slight or great, depending on how well done the meat is cooked. The characteristic changes produced by cooking consist of (*a*) change in color, (*b*) loss in weight, (*c*) contraction in volume, (*d*) changes in fatty tissue, (*e*) changes in structural proteins or connective tissues, (*f*) changes in muscle fibers, and (*g*) change in flavor.

Change in color. During the heating of meat, after a temperature of 50°C is reached the color gradually changes from a deep red or pink to a lighter tint and finally, if a sufficiently high temperature is reached, to brown or gray. Veal and pork are more gray; beef and lamb develop a browner shade. This color change has been discussed in connection with muscle pigments.

Loss in weight. Decrease in weight of meat occurs more rapidly as the cooking temperature is elevated. The loss in weight at higher temperatures may be very striking, for it occurs even when meat is immersed in water. The loss of fat and fluids accounts for the greater portion of the loss in weight during cooking. Factors causing variation in cooking losses are discussed in a later section.

Contraction in volume and change in measurements. The decrease in weight and volume of meat during cooking is one of the outstanding effects of heat upon meat tissues. The shrink which occurs when meat is heated to temperatures above 60°C is not characteristic of all proteins, for eggs do not shrink when cooked. Meigs (95) has pointed out that muscle tissue when heated to 40°C shortens but does not change volume.

McCance and Shipp (93) observed little shrink of meat at temperatures below 60–63°C, although they cite Ferrati's results in which he noted that the percentage in loss of weight rose rapidly between 50° and 70°C and continued to increase slowly with increase in temperature up to 120°C. Meigs (94) found that the sartorius muscle of the frog did not lose weight after remaining 24 minutes in a 0.7% NaCl solution at 50°C, but did lose 20% of its weight in 2 minutes at 65°C.

The temperature of cooking (93) affects both the rate and the extent of shrink. Beef (450-gram pieces from round), cooked under pressure, lost weight rapidly and to a greater extent at 120° than at 100°C (cooked in steam), the difference in weight amounting to about 10% after 6 hours of cooking. In turn meat cooked at 100°C lost more than meat cooked at 80°C, although the difference here was not so great, amounting to less than 5% in 6 hours. However, when smaller pieces of meat were used, 200 grams, there was practically no difference in losses in weight at 80° and 100°C. The loss of weight of meat cooked at 80°C was slow at the start, whereas that at 120°C was rapid.

Although loss of weight is progressive during the cooking of meat, the volume of certain cuts may increase until a definite temperature is reached, after which a decrease occurs. The shrink in volume is never as great as that in weight. The averages which follow (87) are from the muscles of right rounds of two Good and two Choice grade carcasses. Data were taken when the interior temperature reached 90°C. These cuts were then cooked an additional hour and the data again determined.

	Cooked to 90°C	Cooked to 90°C Plus 1 Hour
Total weight loss, %....	34.6	38.9
Volume loss, %........	16.6	25.3
Shrink in length, %.....	22.0	26.0
Shrink in width, %.....	12.0	16.0
Gain in depth, %.......	8.0	3.5

During cooking meat shrinks along the length of the fibers and in width but may gain in the third dimension until cooked extremely well done, when shrink may occur in all three dimensions. Measurements of cuts are difficult to make. The raw meat is pliable and changes shape when it is moved.

Changes in fatty tissue. The fat cells are enclosed in membranes, chiefly of collagenous tissue. Melted fat can escape from cells in which the membrane is cut or broken, or by the changing of this tissue to gelatin during cooking. Some fatty tissue contains denser, firmer connective tissue, more resistant to the release of fat from the cells by cooking, than the tissue around other cells, particularly that in the kidney area.

The surface browning of fat is due to partial charring or breakdown of both connective tissue and the fat.

It has been reported (96) that the ether extract (dry basis) is increased by 35–40% in cooked meat over that in raw meat. It was presumed that this was caused by infiltration of melted fat from the surface of the muscle.

On the other hand, in a study in this laboratory on five muscles from eight animals, it was found that the fat content of the muscle was the same before and after cooking (dry basis). The fat molecule is large, so that it does not seem likely that much infiltration of fat would occur during cooking, particularly when the meat is shrinking and water with salts and other soluble constituents are being squeezed from the interior. It is well known that, in curing meat, the salt, which is a small molecule, takes a long time to penetrate into the muscle from the surface of the cut. However, there is some explanation for these contradictory results.

Chang and Watts (90) found significant differences in the fatty acid distribution of fat from various regions of the same animal. However, they found that only a small amount of the polyunsaturated fatty acids of beef, pork, lamb, and poultry are lost with ordinary methods of cooking. Thus the nutritional value of the important unsaturated acids is not altered appreciably by cooking.

Changes in connective tissue. Changes in connective tissue brought about by cooking have been discussed.

Changes in intracellular proteins and muscle fibers. If cooked to a high enough temperature the protoplasmic proteins of the muscle fibers are denatured. Sartorius and Child (96) have shown that the diameter of the muscle fibers shrinks with increase in temperature up to 67°C. The decrease in the average diameter of the fibers of the semitendinous muscle cooked in an oven temperature of 150°C varied as follows:

Cooked to an interior temperature of....	58°C	67°C	75°C	Raw
Average diameter of fibers, microns......	58.5	52.4	53.5	64.6

No decrease (96) in diameter of muscle fibers was observed between 67° and 75°C, from which it was concluded that the shrinkage under the conditions of cooking employed was complete at 67°C.

Flavor. *Raw meat.* Crocker (91) found that the flavor of raw meat is mostly in the juice. It is weak, sweet, salty, and blood-like, upon which are "superimposed flavors distinctive of the species, food, and environment of the animal."

Cooked meat. The "meaty" flavor (91) developed by cooking meat in water or at low temperature is presumably brought about by breakdown of amino acids of the protein, particularly those of the fibers. The compounds formed during cooking include ammonia, amines (among which are a fishy-smelling amine, an indole-like odor, and a derivative that suggests piperidine), the chemically easily proved H_2S, and acids (low aliphatic acids, such as acetic and propionic). The wide variety of these products suggests that several types of amino acids are changed during cooking. The flavor of meat is principally an odor, a complex combination of small amounts of many compounds which produce a pleasant and fragrant odor.

The "meaty" flavor (91) increases with longer cooking to about 3 hours, then with still longer cooking decreases. "The flavors that developed on cooking were similar for the various meats, again modified by species, food, and environment of the animal, although even these characteristics tended to be lost with prolonged cooking." Lamb leg roasts (92) cooked to interior temperatures of 67°C had odors and taste more distinctive of lamb than similar roasts cooked to an interior temperature of 75°C. The average flavor score (87) of braised beef cuts from one side of the rounds from four animals cooked to an interior temperature of 90°C was 5.9 (10 highest score), whereas those cuts from the other side of the same animals cooked an hour after an interior temperature of 90°C had been reached, scored 4.8. The sulfury flavor was intensified with the longer cooking.

Crocker (91) found that pork is somewhat like beef, but sweeter, more basic, and more sulfury, and with more fatty acids. Lamb is more alkaline than beef or pork, with a strong caprylic or pelargonic odor characteristic of sheep and goats. Chicken flavor is more complex than that of the red meats and varies within muscles of the same bird. The breast is mild, but sour and astringent. The leg meat is stronger and more sulfury.

Bouthilet (89) found that during steam distillation of chicken broth there is dissociation of ammonia which condenses and fixes the volatile flavoring components. The flavor is composed of at least two portions, a sulfur-containing material and a fatty-acid-like material. The flavor was concentrated 10,000 times as strong as in broth. At this concentration it became nauseating. When a little monopotassium phosphate was added an exceedingly strong chicken flavor was developed. Monosodium glutamate and related compounds are not wholly responsible for the chicken flavor (88), as these compounds are not volatile.

Flavor and color of muscle. Hammond (10) suggests there is a relationship between the color of the muscle and its flavor. The depth of color as well as the intensity of flavor of the muscle increases with the age of the animal. Common examples are veal and beef; broilers and mature fowl. Light-colored muscles of poultry, rabbits, and pork are milder in flavor than the dark-colored ones.

Tenderness

Tenderness is one quality universally desired in meat. Since meat is composed largely of muscle fibers and connective tissue, it is reasonable to assume that both have some role in its toughness. Since meat is usually cooked for eating, many factors affect its tenderness. These include not only the inherent factors such as fat content, fibers, and connective tissue but also the aging, processing, and preparation for cooking as well as the cooking process. Tenderness of meat may be altered by physical, chemical, or enzymatic changes produced in the connective tissue and/or muscle fibers.

Means of determining. Tenderness may be measured (*a*) by subjective methods, (*b*) by mechanical devices, and (*c*) by chemical determination of the connective tissue content.

Subjective ratings. Everyone who eats meat notes its tenderness. The most commonly employed laboratory method of determining tenderness of meat is for panel members to score the meat. A partly subjective, partly objective method to compare tenderness of different samples is to count the number of chews to masticate the sample of meat to a determined end point. Preferably, the sample should be sliced on a machine so that the fibers are a definite length in all samples, and samples of the same size should be used. The scorer should standardize the end point of mastication and determine whether to lower the score 1 point for every 15, 20, or 25 chews.

In the paired scoring method (100) paired samples are provided and compared with each other.

Mechanical. Chewing meat involves cutting, shearing, tearing, grinding, and squeezing of the samples. Numerous mechanical devices have been used to simulate chewing. None duplicate all the actions of chewing. These mechanical devices include the iron teeth of Lehmann (78), gauges, penetrometers, and shearing apparatuses. Both gauges and penetrometer needles appear to measure density and compactness. The most commonly used mechanical device at present is a shearing apparatus, perfected by Bratzler (99) and known as the Warner-Bratzler shear.

Chemical. It is accepted, in general, that muscles containing the most connective tissue are less tender than those containing little connective tissue. Many methods (14, 16, 17, 20, 22) have been proposed to determine the connective tissues quantitatively. Connective tissues are difficult to separate cleanly from the protoplasmic proteins. No method is entirely satisfactory. The connective tissue content may not always measure the toughness. For cooking may soften the connective tissues and change much of the collagen to gelatin. Thus connective tissue may have an important role in the tenderness of meat cooked rare, but a very small one in meat cooked very well done.

Factors affecting the tenderness of meat. Factors affecting the tenderness of meat, many of which have been mentioned, include the fat content of the muscle, the connective tissue content, the texture of the muscle, the muscle fibers, and the age of the animal. Other constituents of the muscle may affect the tenderness of the meat directly or indirectly. The mineral content affects coagulation of the proteins, and the amount of lactic acid produced determines the ultimate *p*H reached by the meat.

Fat and toughness of meat. In general, it has been thought that the deposition of fat intramuscularly increases the tenderness of meat. However, studies reported on this relationship vary. At least three groups of workers have reported that better-fattened animals yield more tender meat than the less-well-finished ones. The New York workers (113) used steers, the Wisconsin workers (13) used Holstein cows, and the Iowa workers (106) used three ages of animals; calves, yearlings, and 2-year olds. The shear force (not with the Warner-Bratzler blade) and scores of the Iowa study were closely related. The average shear force values of the cooked longissimus dorsi muscle from the Iowa study follow:

	FEEDERS	FATTENED
Calves, shear force, lb........	39.5	32.4
Yearlings, shear force, lb......	35.4	24.8
2-year olds, shear force, lb.....	36.8	28.6

In a current study it has been found that the dependence of tenderness upon fat content (ether extract) of the interior of the muscle was significant at the 1% level. Data were obtained from 5 muscles from 8 animals of varying ages. It was found that 1 animal and 1 muscle did not conform to the over-all pattern. The psoas major (tenderloin) muscle is always tender. It had the highest fat content of any of the muscles, yet its tenderness was not dependent upon its fat content. The fat content of the muscles from one of the calves was very low, yet the muscles were very tender. Since the fat content is not the only factor affecting tenderness, it should be expected that some animals and some muscles would not conform to the general pattern.

On the other hand, Hankins and Ellis (104) found no significant correlation between the fat (ether extract) content and tenderness of the cooked longissimus dorsi muscle, from which they conclude that "variations in tenderness are caused mainly by factors other than fat content."

A Texas group of investigators (101) in determining the effect of the degree of fattening on tenderness of lamb, used paired lambs (similar in sex, breeding, conformation, and fleece covering, and differing by not more than 2 pounds in initial weight). One lamb of each pair was full fed, the other was limited fed. The full-fed lamb was more tender than the limited-fed lamb in some pairs, but in other pairs the limited-fed lamb was more tender. They conclude, in view of the contradictory results from different pairs in each test, that it seems doubtful that fatness influences tenderness in lamb to any marked extent.

Connective tissue. The ratio of elastin to collagen in muscle is usually small, so that collagen affects the tenderness to a greater extent than the elastin. The effect of heat on connective tissue has been discussed, and other factors will be considered under cooking.

Tenderness as related to texture of meat. Brady (98) studied the diameter of the muscle fibers and the texture of muscles from cows and steers. His conclusions were: the number of fibers in a bundle is a measure of texture; the greater the number of fibers in a bundle the "finer" the texture; texture is an indication of tenderness; and, the finer the texture, the tenderer the meat. Hammond (10) thinks that one of the main factors affecting tenderness is the size of the muscle bundles or "grain" of the meat. The larger these muscle bundles are, the tougher the meat.

Strandine et al. (117) studied 50 beef and 12 chicken muscles. Like Hammond, these investigators connect tenderness of muscle with its texture. They found a correlation "between the histological structure and the tenderness of the muscles; the muscles which had the larger amount of total connective tissues showed the higher shear readings and the lower organoleptic ratings. This connective tissue in the less tender muscles distinctly divided the muscles into prominent fasciculi. On the basis of the size of the fasciculi, and the amount of connective tissue, it was possible to classify beef and chicken muscles."

Age of the animal. It is commonly known that, in general, meat from older animals is tougher than that from younger ones. However, since tenderness is affected by so many factors, it sometimes happens that age is not the dominant factor in determining tenderness of the muscle. Even differences in tenderness of veal carcasses of the same age and grade may be great. In the study on defrosting and cooking frozen meat (92), various cuts from 18 veal carcasses were used. All cuts from 4 carcasses were consistently tough as indicated by low tenderness scores, whereas cuts from 3 carcasses were exceptionally tender.

Means of altering tenderness of meat. Among the possible ways of increasing or decreasing the tenderness of meat are: (*a*) aging, (*b*) mechanical alteration of the tissues, (*c*) cutting the muscle before it is chilled and onset of rigor has started, (*d*) treatment with enzymes, (*e*) freezing, (*f*) change in pH, (*g*) cooking, and (*h*) added substances for cooking such as acid, salts, and sugar.

Aging is one of the most important ways of increasing the tenderness of meat. See page 214.

Mechanical alteration of tissues by grinding, pounding, or sticking to break the connective tissue and muscle fibers is frequently used to increase the tenderness of meat.

Cutting the muscle. Meigs (111) as early as 1912 observed that, if a cut were made across a fresh frog muscle, rigidity occurred at the cut surface and in a few minutes spread to the entire muscle. A similar rigidity has been observed by Lowe and Stewart in the breast muscle of chicken and by Lowe in the longissimus dorsi of beef in which cuts were made shortly after slaughter. The most outstanding characteristic of this rigidity is its slowness in disappearing in normal aging periods. As a result the affected areas of the muscle or the entire muscle remain tough after cooking. The degree of toughness developed appears to depend on several factors, which include the time after slaughter before the cut is made (the muscle is not affected if rigor has developed), the extent of cutting, and the individual animal. Sometimes the rigidity does not develop. It is usually greater if the cut is made soon after slaughter. In a few chickens it was observed when cutting was delayed as long as 60 minutes.

Ramsbottom and Strandine (82) have reported that steaks boned from one side of an animal from a muscle before it was chilled were tougher than steaks cut from the other side of the animal after chilling. They suggest that this may be caused by physical and chemical changes brought about by the boning. That muscle has not lost its response to stimulus as soon as the animal stops breathing has been observed by those who have electrically stimulated a frog's muscle in a laboratory or watched the twitching of muscles in the side of a beef carcass for 1 to 2 hours after slaughter. Toughening of a muscle from cutting is of practical importance when chicken is cut into pieces a short time after slaughter. Since legs and wings can be disjointed by cutting through the skin and tendons without cutting muscle, toughening of a muscle from cutting applies to the breast where removal of the wishbone and dividing the breast into halves involves cutting the muscles. Beef, veal, lamb, and pork carcasses are chilled before cutting.

Treatment with enzymes. All agree that proteolytic enzymes may increase the tenderness of muscle. The difficulty lies in getting the enzyme uniformly distributed throughout the muscles. In poultry this can be done by injecting the enzyme solution into the blood vessels after the bird is killed. This is difficult, and in addition the bird needs to be cooked immediately after the optimum amount of tenderizing has occurred. If the action of the enzyme goes too far a gooey mass that does not resemble meat results. When the enzyme is applied to the surface of cut meat, the surface may become powdery or otherwise changed for a very short distance. These difficulties may eventually be overcome. The use of papain has been suggested to tenderize meat, and it is the proteolytic enzyme used in commercial tenderizers.

Gottschall and Kies (58) found that ground meat is digested rapidly by papain at 55–75°C, but very slowly at room temperature. This would be equivalent to holding the meat in a warming oven or an incubator. They also found that papain applied to the surface does not penetrate solid pieces of meat and is destroyed by cooking.

Hay et al. (105) applied tenderizer to the surface of beef, then stuck the meat from one side to the other with tines of a fork before and after the application, in order to carry the enzyme into the meat. The tenderizer was effective in increasing the tenderness as compared to that of the control cuts, if the treated cuts were left at room temperature for an hour for each inch of thickness, but not if the treated cut was refrigerated. The control cuts were not stuck with a fork.

Freezing. There is no unanimity of opinion regarding the tenderizing of beef by freezing. Ramsbottom (114) found that frozen storage of steaks at −23.3°C (−10°F) or lower for as long as 7 years did not significantly affect the tenderness. Pearson and Miller (113), who worked with steaks, found freezing *per se* did not increase the tenderness of the steaks whereas frozen storage brought about a decrease in tenderness. Shrewsbury et al. (115) found that freezing did not increase the tenderness of pork.

Hall et al. (103) used pork roasts stored at −12°, −18°, and −23°C (10°, 0°, and −10°F) for varying periods of time (12, 24, 40, 52, and

72 weeks). In general, the palatability committee scored the frozen roasts as less tender than the fresh unfrozen ones. The mechanical shear indicated that only the roasts held for 56 and 72 weeks were less tender than the fresh ones.

Lehmann (78) noted that freezing increases the tenderness of beef, the effect being greater in the less tender muscle or "flank" than in the loin muscle. Hiner and Hankins (109) also have reported that the tenderizing effect of freezing varies with the muscle (being very little with neck and shank muscle) and with age of the animal (only the sirloin sample of veal was tenderized). These authors (107) have reported that beef samples stored at 0.6–1.7°C for 5, 15, 25, and 35 days became more tender with longer storage and that this tenderness was further increased by subsequent freezing, but to a decreasing degree as the storage time before freezing increased. Hiner, Madsen, and Hankins (108) also have reported that beef samples cut 1.5 inches thick and frozen at −8°, −23°, −40°, and −81°C increased consistently in tenderness as the freezing temperature was lowered.

Change in pH. Winkler (119) has shown the relation between *p*H and tenderness by using samples of pork and beef and adjusting the *p*H by injections of lactic acid and ammonia. The samples were then stored at 0°C for 4 days, and tests were made on the raw meat. He found toughness to be at a maximum at *p*H 5.0 to 6.0, the meat becoming progressively more tender at lower or higher *p*H levels. These results are interesting in that the *p*H at which the least conversion of collagen to gelatin in a given time and at a given temperature also occurs at 5.0 to 6.0, Figs. 21 and 22. Winkler found the variation in tenderness to be greater with beef than with pork.

Cooking. Some raw meat (112) is tenderer than some cooked meat. The effect of cooking on tenderizing the meat depends upon the balance between the extent of softening the collagen and hardening the muscle fibers. The effect of cooking also depends to a great extent upon the connective tissue content of the meat, the degree of doneness or interior temperature to which the meat is cooked, and the rate of cooking. The protoplasmic proteins of the muscle fibers, after the required temperature is reached, start to coagulate and become harder and tougher. During this period the connective tissue is becoming softer and continues to soften with further heating. There is some indication that after maximum toughness of the fibers is reached, longer cooking or cooking to a higher interior temperature may increase the tenderness of the fibers. Bard and Tischer (97) found that tenderness of canned beef was a direct function of processing temperature within the range 107–124°C.

Examples in the literature illustrate the above comments. Lehmann (78) found that after cooking 3 hours the flank muscle was more tender than the loin muscle. The flank muscle contained the most collagen. The raw longissimus dorsi muscle (110) was more tender than the cooked samples, as determined by pounds for shearing, and, in turn, the roasts cooked rare were more tender than the ones cooked well done. In another study, roasts (rib, loin, and tenderloin) from one side of 8 animals cooked to an interior temperature of 70°C were more tender than those from the other side of these animals cooked to 90°C. The results with braised cuts from the rounds of these animals, in general, gave opposite results to those for the roasts. In another study (87) braised cuts from one side of paired rounds cooked an hour after the interior temperature 90°C was reached were more tender than the cuts from the other side of these rounds cooked to 90°C.

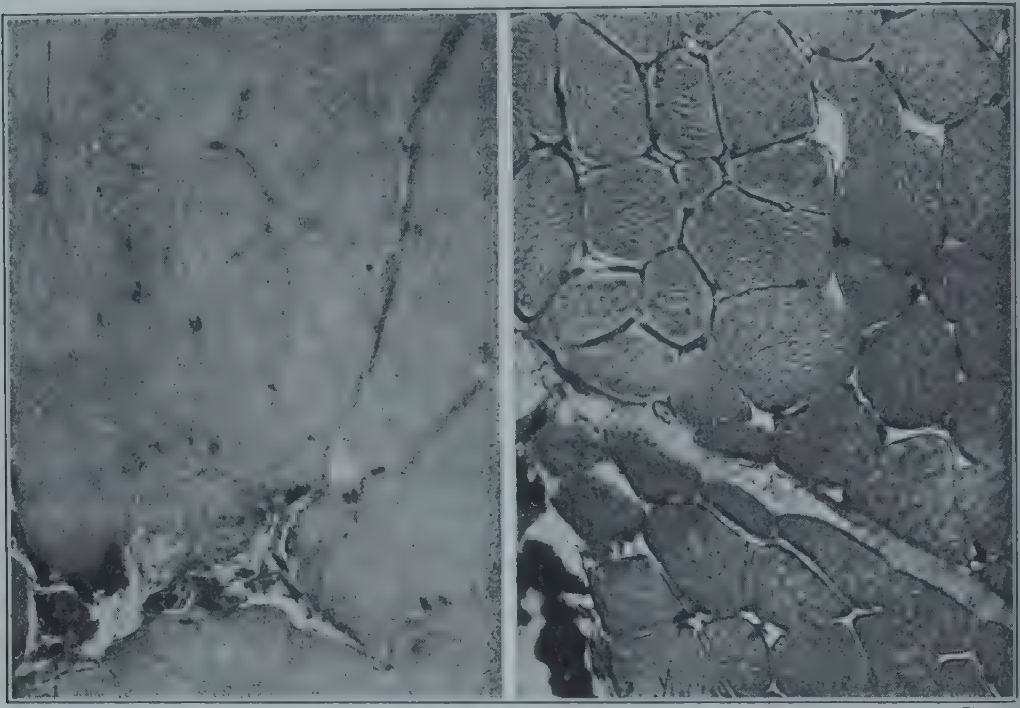
Acid in tomatoes or sour cream is often used with Swiss steaks or stews. Subjective and objective tests, however, have indicated that the paired control without acid is usually as tender as the meat to which the acid has been added. In an ordinary cooking period there is not sufficient time for the acid to penetrate into the meat and bring about its tenderizing effect. This is understandable when meat is considered as a membrane which is more or less permeable to the passage of salt, sugar, acid, and fat. Among the factors affecting the time for the penetration of these substances into the meat are (*a*) the size of the piece of meat, (*b*) the degree of post mortem changes in the meat, and (*c*) the size of the molecule.

A *marinade* composed of water, acid (usually vinegar), and seasoning is often used to increase the tenderness of meat for sauerbraten or similar dishes. Tofte (118) studied the effect of such treatment upon less tender cuts of beef. Muscles were removed from the right and left rounds of the same animal, cut into pieces 3 inches wide, paired, labeled, wrapped, and frozen until used. One cut of each pair was used as a control, the other marinated in 3 parts of water and 1 part of vinegar, 110 cc of this solution being used for each 100 grams of beef. The left cut of each pair was placed in a covered glass container, the marinade was added, and the meat was held 72 hours in the refrigerator. The interior sample after marinating was obtained about halfway between the surface and the center of the cut, which was 3 inches in thickness. The center of the cut would have been less acid. The effect of the marinade upon the acidity is tabulated.

AVERAGE *p*H	BEFORE BRINING	AFTER BRINING	AFTER COOKING
Surface sample...	5.75	4.20	4.69
Interior sample...	5.75	4.71	5.28

The results show that the acid does not penetrate rapidly into the meat, for even 72 hours was not sufficient to bring the acidity of the entire sample into equilibrium. The odor and the change in *p*H show that considerable volatilization of the vinegar occurred during cooking. The pounds required to shear 1-inch samples averaged 23.5 for the marinated portions, 26.1 for the controls.

The microscopic appearance of the marinated samples is shown in Fig. 34. After marinating and before cooking the fibers were blurred, swollen, and somewhat amorphous in appearance, as if they had absorbed liquid. This was borne out by a 10.4% gain in weight during marinating. The lack of definiteness of outline of the fibers was greater in the surface (with lower *p*H) than in the interior samples. There appears to be a relationship between the gain in weight, the histological appearance, and the *p*H of the marinated samples. After cooking, with its attendant loss of weight, the outline of the fibers is more distinct.



Tofte

FIG. 34. Cross sections of semitendinosus muscle of beef after marinating in 3 parts of water and 1 part of vinegar for 72 hours. *Left:* surface sample before cooking. Note swollen fibers. *Right:* surface sample after cooking. Magnification x 300.

Salts. The intracellular proteins are soluble in NH_4Cl, LiCl, NaCl, a mixture of Na_2HPO_4 and NaH_2PO_4, etc. The effect of some of these salts upon the tenderness of beef is as follows:

NaCl. The effect of salt upon the tenderness may depend on the concentration used. A strong concentration of NaCl would dehydrate the meat as well as produce a very salty flavor. Green (102) injected a salt solution into cuts from muscles of the right side of five animals (one an aged cow) so that the amount of salt was about 1.5 grams per 100 grams of beef. The cut gained about 10% in weight. Cuts from the left side were used for controls. The cuts were canned. The salt-injected cuts were scored as having a better flavor and as more tender than the controls.

Tofte (118) found that 3-inch cubes of beef placed in a weak salt brine and stored for 72 hours in the refrigerator gained about 9.7% in weight. The average pounds for shearing after braising was 19.3 pounds for the brined cuts and 22.5 for the controls. The microscopic appearance after brining with NaCl and after cooking was similar to that of the vinegar-treated samples.

Phosphates are found in meat. Smith (84*b*) states: "It is of interest to note that, in cases where the primary aim of cooking is to make meat more tender (as, for instance, in stewing), the required degree of tenderness can be reached more quickly by addition of phosphate, or what amounts to the same thing, since the meat itself contains phosphate, of concentrated stock from a previous boiling. The concentration of phosphate which gives the greatest effect is about 0.2 M, but a quarter of this will have quite an appreciable effect. A suitable mixture of mono- and di-hydrogen phosphates to give a pH between 6 and 7 was employed."

Beef broth from a previous cooking as well as 0.2 M or 0.4 M concentrations of combined NaH_2PO_4 and Na_2HPO_4 have been used for cooking beef cubes in several short studies. The tenderizing results depended partly on the size of the beef cubes. There was no difference in tenderness between control and treated samples of large cubes, whereas the treated samples of small cubes were more tender than the controls. The phosphate-treated cuts were usually scored lower in flavor than the controls at first, then higher as the study progressed.

Cuts from the muscles of a left round were brined in 0.2 M and 0.4 M NaH_2PO_4 and Na_2HPO_4 (using 100 cc of each solution to 100 grams of beef) for 48 hours in the refrigerator, those from the right round being used as controls. The results are tabulated, 10 being the highest possible score:

	TENDERNESS SCORES		POUNDS FOR SHEARING	
	Phosphated	Control	Phosphated	Control
0.2 M..	7.3	5.5	36.4	38.4
0.4 M..	7.4	5.2	41.4	45.7

However, there was considerable variation in the degree of tenderizing in the different muscles, and the gain in weight during the brining period varied from 0.9 to 14.8%.

Calcium salts in excess toughen the curd of cheese and increase the tenacity of gluten. This raised the query as to their effect on meat. The lower concentrations of $CaCl_2$, 0.1 M and 0.2 M, did not appreciably affect the tenderness, juiciness, flavor, press fluid, or shearing strength of cuts from the round immersed in these solutions for 72 hours. The 0.4 M and 0.5 M concentrations imparted a bitter flavor to the meat so that it was unpalatable under the conditions used (100 cc solution to 100 grams of meat), Paul (116).

Sugar in combination with salt may increase the tenderness of meat. Tofte (118) used 7.5 grams each of sugar and salt in 100 cc. of water, 90 cc of this solution being taken for 100 grams of meat. The average gain in weight of these cuts during brining was 5.3%. The average number of pounds for shearing the brined cuts was 17.1 against 23.9 for the controls. The flavor scores were 30 and 21.2 (possible score, 40) for the brined and control cuts, respectively. In microscopic appearance the fibers after brining in sugar-salt and after cooking were similar to those marinated in vinegar.

Addition of Salt for Seasoning

Salt added to the surface of roasts for seasoning (132) penetrates only a short distance during the cooking period, thus seasons only the surface of the roast and the drippings.

Methods of Cooking Meats

The Cooking Committee of the Cooperative Meat Investigations (123) has specified directions for the cooking of meat. These are necessary in order that results in one laboratory may be compared with those in another. In addition they are designed to show slight differences in meat, if any, caused by various production and processing factors.

In experimental work many procedures are tried, and, from the comparison of results, methods of cooking may be formulated that produce the most palatable meat, with the least loss of nutritive factors and the greatest economy of time and fuel.

In general meat is cooked (*a*) by dry heat and (*b*) by moist heat. Dry heat is generally used for tender cuts, such as roasts and steaks. The meat is surrounded by dry air in the oven, under the broiler, over coals, or by hot fat. In general, moist heat is used for the less tender cuts. In moist-heat methods the meat is surrounded by liquid as in stews and casseroles, by steam as in cooking meat in steamers, in foil or other wrap in braising, or in roasting pans with tight-fitting lids.

Frying is a dry-heat method, the layer of cooking fat being shallow or deep. Much of the so-called fried meat is really braised, but frying as a method has been maligned probably to a greater extent than it deserves.

The tender cuts. In general tender cuts include the prime rib roasts, steaks or roasts from the loin and sirloin, leg of lamb, fresh pork hams, and pork, lamb, and veal chops.

Less tender cuts. The less tender cuts are used for pot roasts, Swiss steak, braised meat dishes, stews, and soups. If ground, the meat is cooked as a tender cut.

The less tender cuts are usually cooked by moist heat and at temperatures at or near the boiling point. It is generally agreed that a slow rate of heat penetration, which necessitates long, slow cooking, increases the tenderness of meat more than rapid cooking, but the meat is also less juicy. If the connective tissues are entirely dissolved, the meat is not sliceable.

Covered vs. uncovered pans. For roasting meat at home the uncovered pans are recommended. In general the results indicate that the cooking time is somewhat longer, but the cooking losses are less (see section on cooking losses), the nutritive losses less, and the meat more palatable.

The use of skewers. For a time metal skewers were suggested as a means of shortening the time for cooking meat. Meat conducts heat slowly, metal rapidly. The skewer has a pencil-shaped or broad point which is pushed into the meat. This point is attached to a large expanse of metal outside the roast to conduct the heat down the metal point into the roast. Morgan and Nelson (129) and Cover (125) have reported results with skewers. Cover used paired round, armbone chuck, and standing rib roasts. These roasts were cooked at an oven temperature of 125° to an interior temperature of 80°C. The use of skewers reduced the cooking time by about 30–45% and decreased the weight losses during cooking by about 35%. However, when the results were tabulated the percentage of panel members voting the control as the more tender was 86% for rounds, 79% for chuck, and 64% for rib roasts. Thus greater tenderizing occurred by longer cooking, particularly in the cuts with the higher collagen content.

Pressure cooker. One question often asked is why meat cooked in a pressure cooker at a high temperature is tender and not dry. The answer is that in addition to temperature and time of cooking the result is also affected by the pressure. There would be a far greater tendency to dry the fibers at a high temperature and in a partial vacuum.

Cooking Temperatures

The statement is often made that high cooking temperatures increase the toughness of meat whereas low ones produce tender meat. This concept needs revision. For under most conditions the time of cooking rather than the cooking temperature appears to be the determining factor affecting the tenderness. Other factors that may affect the result are the stage of cookery and what is meant by a high and low temperature.

When meat is cooked to the rare or medium stage, most laboratories engaged in meat research have more than one example like the following. In cooking 9 pairs of beef rib roasts to an interior temperature of 63°C the tabulated result was obtained.

Oven temperature, °C..........	125	200
Means of shearing tests, lb......	23.3	22.9

Cuts cooked in air. When cuts are cooked in air, the temperature of which is 90–125°C, and cooked well done, the cuts are usually more tender, for the required cooking time is longer, than similar cuts cooked at 150–200°C.

Cover (124) compared the effect of low and high oven temperatures upon one palatability factor (tenderness) of roasts. The roasts were divided into three groups on the basis of the difference in time required to cook the roasts at the low and high oven temperatures. This division into groups when taken in connection with the percentages of judgments favoring the lower oven temperature as producing tenderer meat indicates that time of cooking rather than the oven temperature is the important factor in producing tender meat at the lower temperature. The results are given in Table 18.

TABLE 18

Effect of Oven Temperatures (125°C and 225°C) upon the Tenderness (by Paired-Eating Method) of Paired Roasts, with Difference in Time Required for Cooking at Low and High Oven Temperatures (*Cover*)

Cut	Interior temperature °C	Lower temperature produced tenderer meat %	Difference in time for cooking at the two temperatures min
Group I			
Round-bone chuck, beef......	80	96	370
Beef rump.................	80	93	309
Group II			
Half ham fresh pork..........	84	75	195
Beef ribs 9–10–11...........	80	69	184
Group III			
Leg of lamb................	76	51	105

Cover then started a second study in which 22 pairs of ribs and 21 of chuck beef roasts were cooked at oven temperatures of 125°C and 225°C to an interior temperature of 63°C. The time-temperature curves in the previous study had shown that flattening occurred in the curve after the interior temperature reached 63°, a longer time being required for each degree rise in temperature.

Cuts cooked in water. To compare simmering vs. boiling temperatures, Onãte (130) used a pair of rounds from a Commercial grade carcass. The dissected muscles were placed on trays and partially frozen to facilitate evenness in cutting. The muscles were then cut into slices 1 inch thick on a band saw. The slices were again partially frozen and sawed into 1-inch strips. The strips were cut into 1-inch cubes. Cubes from the right and left muscles were wrapped separately. Cubes from one side of the animal were simmered (90–95°C) whereas the corresponding cubes from the other side were cooked in boiling water. The cooking utensil was covered. Each of the following figures is the average of 26 tests. (Scores 1 to 10, with 10 high.)

TEMPERATURE OF COOKING	SIMMERING	BOILING
Weight loss, %	40.1	41.1
Cooking time, min	294.0	162.0
Fuel used, cu ft	4.2	3.75
Tenderness scores	6.7	6.5
Shear force (on 5 cubes), lb	14.2	14.3
Juiciness scores	3.8	4.0
Press fluid, %	25.3	25.6

Advantages of low temperatures. In general, lower cooking temperatures result in more uniformly cooked meat and in less cooking losses. The effect of temperature upon cooking weight losses is illustrated in the accompanying table. Legs of lamb (92) were cooked to an interior temperature of 75°C, and 11 legs were used in each test.

Oven temperature, °C	120	150	175
Weight loss, %	21.6	23.1	25.8
Cooking time, min	276	188	156

When the time of cooking is unusually long at the lower temperature, the weight losses during cooking may be high. Compare the above results with legs of lamb with those that follow. The data were obtained with rump half of veal leg roasts (92). The cuts were cooked to an interior temperature of 85°C. Scores were 1 to 7, with 7 high. Each figure is the average of 6 tests. The veal leg roasts cooked at 120°C were more tender than those cooked at 150° and 175°C, but were also less juicy.

Oven temperature, °C	120	150	175
Weight loss, %	38.4	35.6	34.2
Cooking time, min	668	356	238
Fuel used, cu ft	58.5	43.9	45.1
Tenderness scores	6.5	5.6	5.7
Juiciness	3.5	4.5	4.7

The optimum cooking temperature. The temperature that produces the most palatable product with a minimum weight and nutrient loss in a reasonable cooking time with a small amount of fuel could be called the optimum cooking temperature. This temperature may vary for different methods of cooking, for different cuts and kinds of meat, for different thickness of cuts (as for steaks cut 0.5, 1.0, and 2.0 inches in thickness), and with the stage of cookery (as rare or well done). The optimum cooking temperature has not been determined for all these conditions.

Roasts. Based on cooking a large number of roasts (92) from beef, veal, lamb, and pork, and for both frozen and thawed roasts, the optimum oven temperature appears to be 150–160°C (about 300–325°F). At lower temperatures (120°C or lower), the cooking time is longer and often the weight loss and fuel consumption are greater than at 150°C. Roasts cooked at the lower temperatures, if cooked well done or very well done, are tender but also dry. At higher temperatures (175°C or higher), the cooking time is shorter but the amount of fuel needed is greater and the cooking weight losses are usually higher. Roasts cooked rapidly are juicier than those cooked very slowly.

Stages to Which Meat Is Cooked: Rare, Medium Well Done, and Very Well Done

Beef or lamb may be cooked rare, medium, or well done. Pork should always be cooked well done. Veal and poultry are usually cooked well done.

Rare meat. Sprague and Grindley (133) have suggested, for convenience, that meat whose interior temperature has not gone above 55–65°C be called rare. The most outstanding characteristic of rare meat is its color. Nearly all the interior may be a bright red, or the gray may extend to varying depths so that only a small spot in the center is red. The uniformity of the color is connected with the cooking temperature: the lower the temperature, the more uniform the color. Other factors affecting the color are the extent to which the meat has been aged, the kind of meat, and variations of individual animals. Beef ripened 40–60 days is grayer at the same interior temperature than that not aged; veal is grayer than beef. Beef from some animals tends to stay red and change color less readily than that from most beef carcasses.

Rare meat is juicier than well-done meat. When meat is carved, juice a shade or two darker red than the muscular tissues may flow from the cut surfaces. Sartorius and Child (96) found that both the total moisture and press fluid decreased with each increment in interior temperature, except that there was no decrease in press fluid between 58° and 67°C for beef roasts. That the juiciness of the meat is greater at the center of the slice than near the exterior was shown by Child and Moyer (122). The press fluid decreased significantly between slices, the amount increasing progressively from exterior to center of the semitendinosus of beef cooked to 58°C. However, this was not true of the longissimus dorsi muscle of pork cooked to 84°C.

Since little shrink in volume occurs until the temperature is beyond 63°C the volume of rare meat has changed but little; but since the exterior temperature is higher than that of the interior, the outer muscular tissues contract, giving the cut surfaces of the longissimus dorsi muscle of beef rib roasts a puffy or outward-bulging appearance.

Medium-done meat. According to Sprague and Grindley (133), meat which has reached an inner temperature of 65–70°C is medium well done. The outstanding characteristic of medium-done meat is also the color, which is more pink or rose, less red; as the medium-done roast verges into the well-done roast it acquires a grayish cast. The volume shrinks slightly, less juice follows the carving knife, and the cooking losses are greater than for rare meat.

Well-done meat. Sprague and Grindley (133) suggest that beef which has attained a temperature of 70–80°C be called well done. Since the color of cooked meat varies with different conditions, the division into rare, medium, and well done on the basis of inner temperature of the meat is only arbitrary and not always satisfactory. For example, meat that has not been aged and has cooked quickly may have considerable pink color, even at 75°C. Roasts may be cooked to interior temperatures of 84–85°C. The color is uniform gray throughout. The shrink is great, being greater for the higher interior temperatures, and the meat is less and less juicy until a point is reached at which no juice will flow when the meat is carved. Beyond this stage the meat becomes denser. Braised meat is often cooked to interior temperatures of 95°C or even higher. However, on account of evaporation it is extremely difficult to get the temperature of meat above the boiling point of its juices.

Very well done. Braised meat (from less tender muscles) and particularly that from older animals may be cooked very well done, to an interior temperature of 90–95°C and in some instances even higher. Meat is cooked to these high interior temperatures to continue softening of the connective tissues, and possibly to soften the muscle fibers. Such meat is characterized by a high weight loss during cooking, dryness of the fibers, and a tendency for the muscle fibers to fall apart, particularly if the cut is held at 90°C or above for a long time.

Degree of doneness as affected by rate of heat penetration. The extent of the changes produced by heat in muscle fibers varies with the rate of cooking. If paired beef rib roasts are cooked at oven temperatures of 125° and 200°C to an interior temperature of 63°C, the roast cooked at 200°C will appear more like rare meat (more red and less pink), whereas the roast cooked at 125° is more well done. In other words, the roast cooked at 200° would need to be cooked to a higher interior temperature than 63°C to have the meat proteins denatured to the same extent as those in the roast cooked at 125° to an interior temperature of 63°. Custards cooked rapidly need to be cooked to a higher temperature to thicken than those cooked slowly. This same principle is also applied in pasteurization. In flash pasteurization the temperature is much higher in order to coagulate bacterial protein to the same extent as in ordinary pasteurization.

Factors Affecting the Time Required for Cooking Meat

Directions for cooking often state the time of cooking in terms of minutes per pound. At best this can serve only as a poor guide, for the following factors affect the time required to cook the meat: (*a*) the method of cooking; (*b*) the cooking temperature; (*c*) weight, surface area, and the shortest distance to the center of the thickest portion of the meat; (*d*) the stage to which the meat is cooked—rare or well done; (*e*) the composition of the meat; (*f*) the degree of post mortem changes; and (*g*) the initial temperature of the meat.

Method of cooking. If the cooking mediums are the same temperature, the time of cooking depends largely upon the rate at which heat is conducted in the particular medium being used. Meat may be cooked in water, steam, air, or fat. The specific heat (128, 131) of water is 1, steam 0.48, air 0.24, and oil 0.41–0.43. Meat reaches a definite interior temperature very much faster in water than in air of the same temperature. See Cover's results, Table 19. Covered containers, in which no water was added initially, form steam from fluids escaping from the meat. This steam conducts heat more rapidly than air; hence under otherwise standardized conditions covered meat cooks in a shorter time than uncovered meat.

TABLE 19

COOKING TIME AND LOSSES OF PAIRED ROASTS COOKED IN WATER AND IN AN OVEN AT THE SAME TEMPERATURE, 90°C (*Cover*, personal communication)

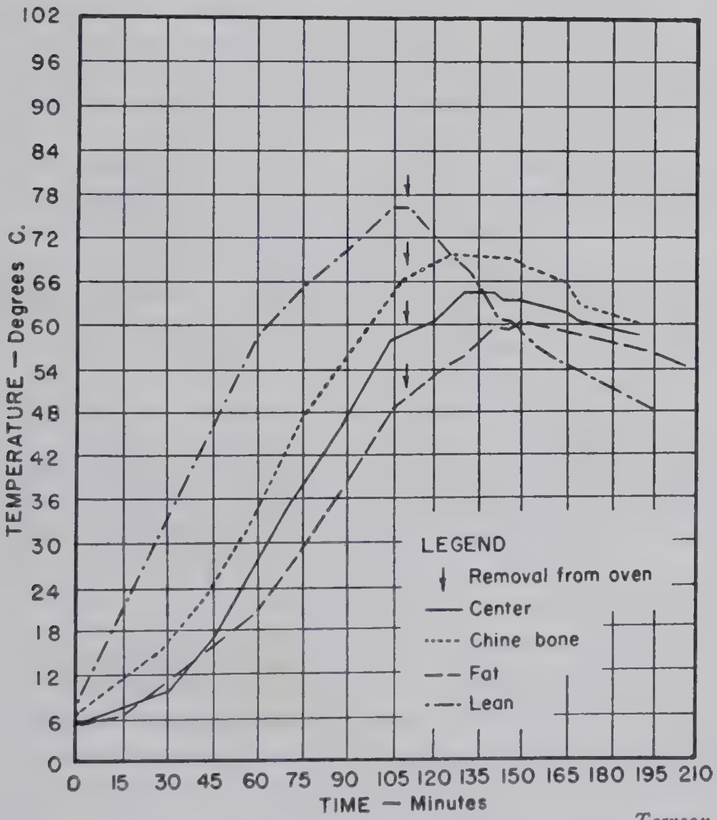
Cut	Interior temperature °C	Number of paired roasts	Cooking time		Cooking losses	
			Oven hr	Water hr	Oven %	Water %
Bottom round...	80	8	26.4	1.9	41.0	26.1
Top round......	80	8	31.8	2.4	42.3	29.9

The cooking temperature. The higher the cooking temperature the more rapidly will a piece of meat reach a definite temperature, for, with a higher temperature at the surface, the more rapidly heat will penetrate to the interior of the meat. As cooking temperatures may vary many degrees, this factor causes a wide variation in the time required.

Weight. Surface area. Shortest distance to the thickest portion of the meat. As the size of a piece of meat increases, its weight increases in greater ratio than its dimensions. This can be illustrated readily. Suppose a 1-inch cube weighs 1 ounce. It contains 6 square inches of surface and the distance from the sides to the center is 0.5 inch. If the sides of the cube are increased to 10 inches, the surface area is increased to 600 square inches, its weight to 1000 ounces, and the distance to the center is 5 inches. It will take 10 times longer for the interior temperature of the large cube to reach a definite temperature, but its weight is 1000 times greater. Although all pieces of meat are not cube shaped, similar relationships hold among the weight, surface area, and distance o the center of similar pieces. From this it can be readily seen, if other onditions are standardized, that large cuts (roasts, hams, legs of lamb, eal leg roasts, rolled roasts, poultry) will require fewer minutes per ound than smaller similar cuts.

Stage to which the meat is cooked. If all other conditions are tandardized, cooking meat rare requires a shorter time than cooking it edium or well done.

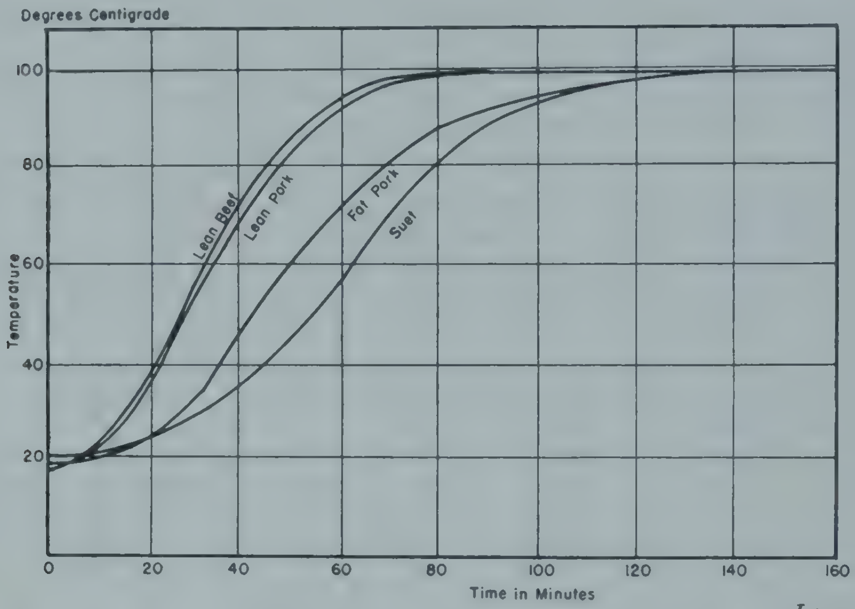
The composition of the meat. Towson (135) cooked paired prime eef ribs at 125°C and 200°C to interior temperatures of 63°C. Each oast consisted of 2 ribs and averaged 4 inches in width. Temperatures uring cooking were recorded from 4 points in each roast. These points ere (*a*) the center, which was 2 inches from either cut surface of the ongissimus dorsi muscle, (*b*) 0.5 inch below the chine bone, (*c*) 0.5 inch rom the cut surface of the lean, *i.e.,* the longissimus dorsi muscle, and *d*) 0.5 inch below the surface of the fat over the top of the roast. When he fat layer over the top of the roast was deeper than 0.5 inch, so that the hermometer bulb was embedded in the fat, the heat penetrated the 0.5-nch layer of fat more slowly than the 2 inches of lean. See Fig. 35.



Towson

Fig. 35. Temperature in four sections of an 11–12th beef rib roast cooked at 00°C. Each temperature, except that at the center, is ½ inch below the surface. ote that the temperature rise in the lean ½ inch below the surface is more rapid an through a fat layer of the same depth.

To obtain data on the rate of heat penetration in muscular and fatty tissues, pint jars (3 inches in diameter and the type used for canning) were filled with lean beef, lean pork, fat pork, and suet. A pound of the cubed material was placed in each jar with the exception of the suet. Suet, in most instances, was packed as tightly as possible without pounding it. A thermometer bulb was inserted through rubber corks in the lids of the jar and processor to the center of the jar. The jars were placed in a processing container (all four in the same container) and heated in boiling water and steam for 3 hours. The results are shown in Fig. 36. In only two instances did the slope of the curve for suet rise rapidly after its melting point was reached. In these two tests the suet was tamped tightly into the jar in order to put in a pound of the suet. This broke the connective tissue membranes, so that the fat upon melting escaped readily from its enveloping connective tissue.



Lowe

FIG. 36. The rate of heat penetration through lean beef, lean pork, fat pork, and suet packed in pint jars and heated in a boiling water bath for 180 minutes. Average of 37 tests.

Thille, Williamson, and Morgan (134) in cooking three-rib beef roasts at an oven temperature of 225°C (which was dropped to 210°C in 10 minutes) to an interior temperature of 65°C came to the conclusion that exterior fat, because of the change in heat conductivity of fat as it passes from the solid to the liquid condition, speeds up the rate of heat penetration, but interior fat may retard it.

Initial temperature of the meat. A longer time is required for cooking when the initial temperature of the meat is low than when it is higher. Meat having a temperature of 0–5°C requires a longer time than meat having an initial temperature of 20°C. Meat still frozen when cooking is started requires a long cooking time, part of the heat being used to melt the ice before the temperature can be elevated above the freezing temperature of the meat.

Rise of Interior Temperature of Meat after the Cooking Process Has Been Stopped

When a roast is removed from the oven or a piece of cooked meat is removed from the cooking utensil the temperature in the interior may continue to rise. Heat is carried to the interior of the meat by conduction, that is, from fiber to fiber. When the cooking process is stopped the temperature of the meat half way to the center is higher than the temperature at the center. This heat is conducted both toward the center and the outer edge of the meat, and as a consequence the temperature at the center of the meat rises.

The factors that may determine the extent of this rise in temperature after removal from the oven are: (*a*) the cooking temperature; (*b*) the inner temperature of the meat when the cooking process is stopped; (*c*) the size of the piece of meat; (*d*) the composition. It must be remembered that each of these factors may have an influence on the temperature rise of the same piece of meat, and that under some conditions one factor may influence it more than another. Thus they cannot be considered separately, for the high cooking temperature of a steak or roast may affect the temperature rise more than the size. Yet under some conditions size is a greater factor in determining temperature rise.

Cooking temperature and temperature rise after the cooking process is stopped. The higher the cooking temperature the greater the tendency for a rise in the inner temperature of the meat. A higher cooking temperature produces a higher surface temperature, and consequently results in a higher rise at the interior after the cooking process is stopped.

Inner temperature. The lower the inner temperature at which the cooking is stopped, the greater is the tendency for the rise of inner temperature. This is because with a low inner temperature there is a wider variation between the inner and surface heat, which results in greater rise of inner temperature. At 75°C or above there is usually little or no rise in temperature after cooking is stopped. It is impossible to raise the inner temperature of meat above 100°C, unless the product is completely charred, for heat supplied in amounts greater than the amount needed to reach the boiling point of the juices is used in evaporating the liquid.

Size. In larger pieces of meat, the size of the piece is not so important a factor as those mentioned above in affecting the temperature rise of the interior after cooking has been stopped. But a piece of meat may be so small or thin that the inner temperature does not rise after the cooking process is stopped, because of the rapid cooling from the surface.

Composition and duration of temperature rise. No definite relation has been established between composition of the meat and the extent of the inner temperature rise after cooking. Composition does seem to affect the duration of the temperature rise more than the extent. Meat containing a great deal of fat and meat that has a very thick layer of fat on the surface, ¾–1 inch or more, requires a long time for the inner temperature to reach its maximum point. A roast with such a layer of fat may take as long as 1 to 1½ hours to reach its maximum inner temperature after the cooking process is stopped, whereas a lean roast of the same shape, and cooked under the same conditions, may take only 12 to 30 minutes.

Factors Affecting the Losses That Occur During the Cooking of Meat

The total loss that occurs during the cooking of meat includes the losses known as drippings and the volatile losses. The greater part of the volatile loss is from evaporation of water. It includes volatile aromatic substances and may include volatile decomposition products of fat and protein. The drippings include fat, water, salts, and both nitrogenous and non-nitrogenous extractives.

Stage of cookery. The more well-done meat is cooked the greater the cooking losses, other conditions being standardized. This is illustrated by the losses for 12 pairs of two-rib (11–12) beef roasts cooked at 150°C.

	Interior Temperature When Removed from Oven °C	Cooking Time min	Cooking Losses %
Rare.........	55	102	7.7
Well-done.....	75	167	16.6

Contrast the cooking weight losses of the roasts given above with the very well-done braised cuts (87). Each figure is an average obtained from 6 muscles of 2 pairs of rounds. Data were obtained when the cuts reached an interior temperature of 90°C. The cuts were then cooked an hour longer, and the cooking weight losses were again obtained as tabulated.

Grade	Cooked to 90°C %	Cooked to 90°C Plus 1 Hour %
Choice......	34.4	38.2
Good.......	35.0	39.6

Composition of meat, grade. The ratio of evaporation losses to drippings losses is higher for lean meat and lower for fat meat. Since, in general, increased fat content is associated with increase in grade, cuts from higher-grade carcasses usually have greater fat losses. Alexander and Clark (120) found this relationship to hold for leg of lamb and beef roasts, though there was considerable variation in the beef.

Surface area. The surface area of a cut of meat of a given weight depends upon its shape. Compact pieces with correspondingly small surface have smaller losses than irregular-shaped pieces with greater surface area.

Degree of ripening. Alexander and Clark (120) in cooking legs of lamb after aging 2–24 days found that increasing the ripening period decreased the cooking losses. Moran and Smith (112) found the average cooking losses of top round, bottom round, and loin after ripening 3, 7, and 16 days to be 29.5, 24.1, and 23.0%, respectively. Hanson, Stewart, and Lowe (136) found that with broilers the cooking loss decreases significantly with ripening. However, McCance and Shipp (93) using meat from the leg and back of rabbit obtained opposite results.

Cooking temperature. In general, the higher the cooking temperature the greater is the cooking loss. This is illustrated by the results obtained with 8 pairs of two-rib (7–8) beef roasts.

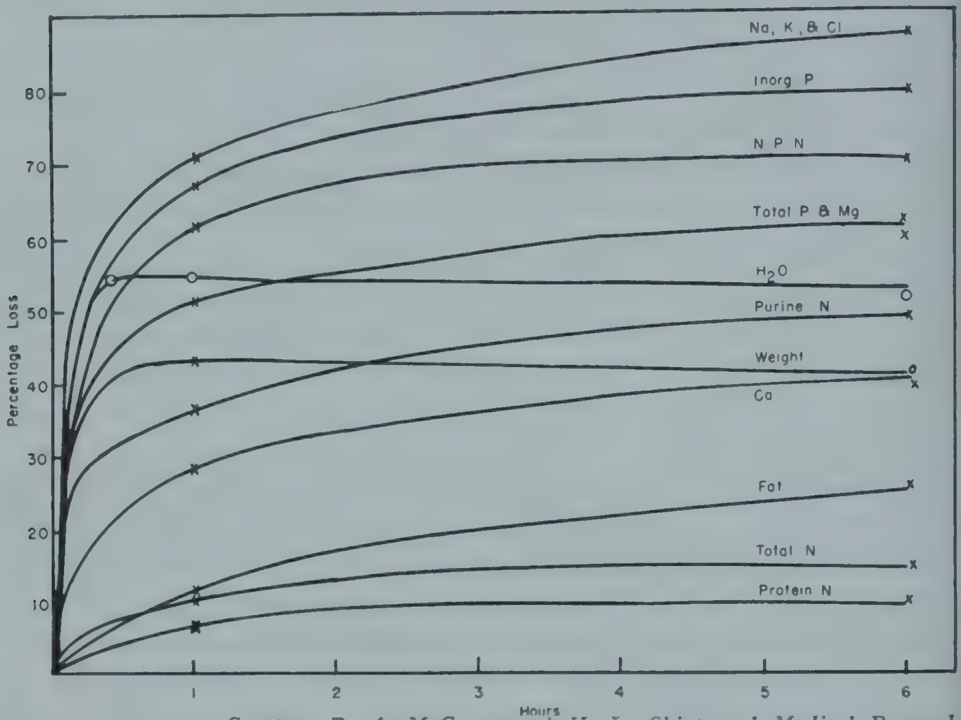
Oven Temperature °C	Time of Cooking min	Total Cooking Loss %
125	212	9.1
200	120	18.6

McCance and Shipp (93) compared the effect of temperature upon cooking losses in loin, liver, kidney, tripe, and brain of beef. The pieces of meat of varying size were cooked in steam at 80°, 100°, and 120°C. Increase of temperature increases both the rate and the extent of the cooking loss. The extent of cooking loss is greater for 450-gram pieces of beef at 100°C than at 80°C, and in turn definitely greater at 120°C than at 100°. The percentage loss in weight varies with different tissues. For 50-gram pieces of liver there is no difference in extent of shrink between 80° and 100°C, but a difference between 100° and 120°C. For 50-gram pieces of tripe the loss is twice as great at 120° as at 80°. Brain tissue has little loss at 80°C even after 6 hours' cooking. At 100°C the loss is considerable and at 120° extensive.

Method of cooking. The method of cooking influences not only the total but also the relative proportions of the different constituents lost during cooking. Meat may be cooked in water, in steam, in air, and in fat.

Water. McCance and Shipp (93) used 50-gram ½-inch strips of loin, which were dropped into 500 cc of boiling water. The cooking was continued for 6 hours, pieces being removed at intervals for determination of losses. The results are shown in Fig. 37. The loss of weight and water is rapid for 30 minutes, then practically ceases. Since the pieces are small the temperature throughout the meat rises very rapidly. The total-weight-loss curve practically parallels the water-loss curve throughout the entire cooking period, being slightly less. The losses of Na, K, and Cl are over 50% at the end of 30 minutes and more than 80% at the end of 6 hours. The loss of inorganic phosphorus follows these constituents closely, and next comes non-protein nitrogen. The total P and Mg curve crosses the water-loss curve at 1.5 hours. Ca and purine N losses are less than the water loss. Fat, total N, and protein N losses are small and decrease in the order named.

Further work by McCance and Shipp indicates that the losses of the soluble constituents when meat is cooked in water are due to two factors, leaching and shrink. During shrink of the meat water exudes, carrying soluble constituents with it. During cooking of 50-gram pieces of loin for 6 hours over 80% of the soluble salts are lost. Of this amount leach or diffusion accounted for 38%, shrink in volume for the remainder.



Courtesy R. A. McCance and H. L. Shipp and Medical Research Council, London. Figures 37, 38, and 39 published with permission of the controller of His Britannic Majesty's Stationery Office

FIG. 37. The losses from lean beef, cut in ½-inch strips (about 50 grams each) and cooked in 500 cc of water which was boiling when the meat was added. Each point is the average of four determinations. From *The Chemistry of Flesh Foods and Their Losses on Cooking.*

Starting in hot vs. cold water. No loss of water (93) occurs from 50-gram pieces of loin when put into cold water until the temperature of the cooking water reaches 60°C. However, diffusion of salts occurs at a low temperature. The loss of weight, salts, and water is initially more rapid when the meat was started in hot water, but after 100 minutes of cooking the losses are the same.

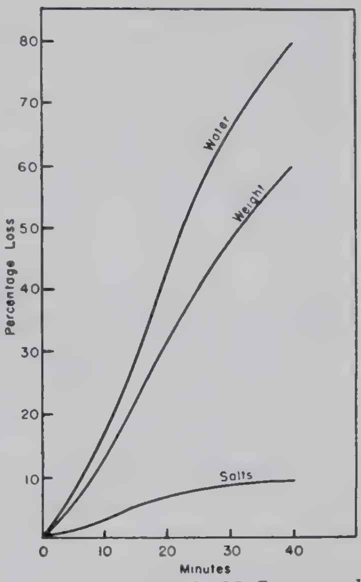
Air. In Fig. 38 are shown the losses in weight of 50-gram pieces of beef heated in air on wire gauze in an oven at 215°C. The pieces are dehydrated and almost charred in 40 minutes. The water loss is continuous;

he curve representing it is almost a straight line. The salt loss is about 10% of the total salts. Fish loses weight at approximately the same rate nd extent. During evaporation the juices are brought to the surface of he meat. The salts crystallize on the surface upon evaporation of the vater. When the juices are brought to the surface and drip off the meat aster than they can be evaporated, salts are lost in the drippings.

Water (93) constitutes the major portion f the loss, around 90%, from these pieces of eef cooked in air. However, it should be tated that these pieces of meat had no visible at and that in actual practice when meat is ooking in air the fat loss increases in direct atio to the fat content of the meat so that in very fat piece of meat the fat may account or 40% or more of the total cooking loss.

Effect of size of pieces on cooking losses. The data (93) shown in Fig. 39 are for 1650-gram pieces of beef roasted in an oven at 175°C. The curve representing the water oss is practically a straight line. For consumption a 4-pound piece of meat would not be cooked longer than 3 hours for an extremely well-done roast. The loss of salts is at first negligible, but after the temperature has become more nearly constant throughout the meat the juice is expressed faster and the salt loss increases.

Steam. The losses (93) for beef cooked in steam are the same as for beef cooked in water. However, fish loses more weight in steam than in water. The salt loss for beef cooked in steam is much greater than for beef cooked in air, but less than when it is cooked in water. The salt loss shown in Fig. 38 would have been 50% instead of 10 had the pieces of meat been cooked in steam. The steam carries the salts into the juices; they crystallize on the surface when the meat is cooked in air.

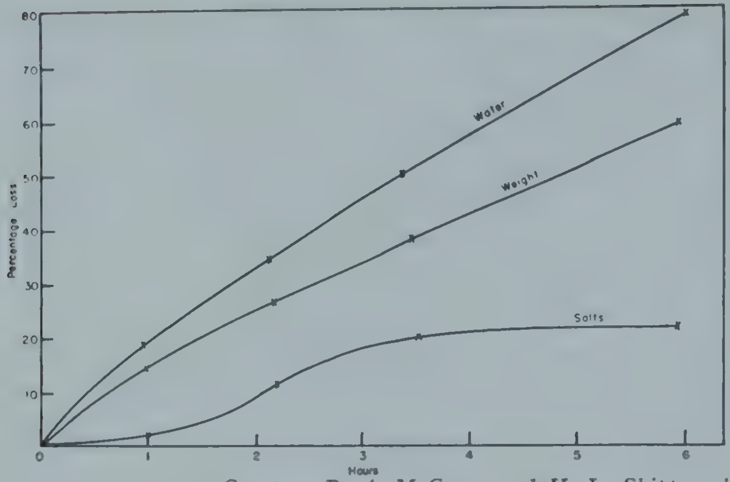


Courtesy of R. A. McCance and H. L. Shipp and Medical Research Council, London

FIG. 38. Effect of cooking in air and size of pieces on cooking losses; 50-gram pieces of beef were cooked in a gas oven at 215°C for 40 minutes. From *The Chemistry of Flesh Foods and Their Losses on Cooking.*

Frying. The losses of various constituents when fish is cooked by different methods are shown in Table 20. The weight and water loss tends to be high in frying, but the losses of other constituents are low. The fact that Ca and Mg are somewhat more soluble in fat than Na and K is reflected in the losses when the fish is fried.

Covered vs. uncovered pans for cooking meat. Grindley and Mojoinner (126) state: "The total losses were greater when the meats were roasted in a covered pan than when they were cooked in open pans, owing chiefly



Courtesy R. A. McCance and H. L. Shipp and Medical Research Council, London

FIG. 39. Pieces of lean beef, 1650 grams each, were cooked in a gas oven at a temperature of 175°C. The cooking losses are shown. From *The Chemistry of Flesh Foods and Their Losses on Cooking.*

TABLE 20

COMPARATIVE LOSSES WHEN FISH IS COOKED BY DIFFERENT METHODS
(*McCance and Shipp*)

	Herring		Catfish		
	Boiled %	Fried %	Boiled %	Steamed %	Fried %
Weight	13.0	40.0	28.0	24.5	24.0
Total nitrogen	9.9	0.05	6.6	5.6	0.1
Purine nitrogen	12.7	2.4	17.6	15.8	1.7
Non-protein nitrogen	33.0	1.1	35.0	23.6	2.1
Na	38.8	1.5	39.5	31.0	4.4
K	37.3	1.0	39.6	29.8	3.4
Ca	5.0	1.4	21.6	16.4	6.4
Mg	21.0	2.3	27.5	23.0	5.2
P	22.0	0.6	30.0	24.0	2.9
Cl	50.0	2.5	43.5	35.0	2.3

Courtesy of Medical Research Council

to the increased amount of water removed. In the same time and at the same temperature the meat was more thoroughly cooked in the covered than in the open pan, possibly because the temperature of the meat was higher in the closed pan." However, they based their conclusions on results of experiments with 1 covered and 15 open pans.

Latske (127) found cooking losses greater in covered than in uncovered pans. The Cooking Committee of the Cooperative Meat Investigations uses uncovered pans for cooking all experimental roasts and advices their use in the home. In general the cooking losses are less and the meat more palatable in the uncovered pan. The cooking time is shorter in the covered pans.

McCance and Shipp (93) state that, if evaporation is the cause of the small loss of salts compared with the loss of water, striking differences should be observed, since evaporation should be greatly reduced in a container. Two effects of reducing the evaporation might be predicted: (*a*) there should be a greater loss of salts in the closed than in the open pan, and (*b*) owing to the reduction of evaporation from the surface of the meat, the latent heat of evaporation should be conserved in the meat and the enclosed meat should therefore cook more quickly. Their results are given in Table 21.

TABLE 21

Cooking Losses in Covered and Uncovered Pans for Roasts of Pieces of Loin Muscle Weighing about 700 Grams Each (*McCance and Shipp*)

Time of Cooking	Covered roast			Uncovered roast		
	Losses of		Water/salt ratio	Losses of		Water/salt ratio
min.	Water %	Salts %		Water %	Salts %	
40	30.5	26.0	1.14	22.5	7.5	3.00
75	53.0	45.0	1.16	49.0	22.2	2.20
90	51.6	41.0	1.26	43.0	15.0	2.90

Frozen Meat and Poultry

See Chapter 4, page 100.

POULTRY

The dressed or New York dressed weight is the weight of the bird after it is bled and the feathers are removed. Market prices in retail shops are usually for the dressed weight. The drawn weight is the weight after removal of the head, feet, and viscera.

Cooking of Poultry

In cooking poultry, one is confronted with the problem of cooking tender and less tender muscles. As a result, if the bird is cooked whole, when the breast is at its prime, the thigh and leg muscles may be slightly tough. The skin is another problem, particularly in roasting. If it is moist and tender, the appearance is less attractive; if brown and crisp, it is slightly or very tough. If the skin is not consumed this point is not important.

Roasting. The degree of fatness and its distribution, the degree of post mortem changes or ripening, the age, and the size may affect the cooking time and cooking losses of roasters. In addition, breed, sex, and the feed the bird has received may have some effect. Hence, for fair experimental tests the cuts should be paired. To do this Lowe and Keltner (137) divided roasting chickens into halves, the halves being compared to determine the effect of the cooking temperature, covering the pan, and basting on cooking losses, cooking time, and palatability of the meat.

Cooking temperatures. Halves of roasters were cooked in uncovered pans at 125°C (250°F) and 175°C (350°F). The doneness was determined by placing a thermometer bulb in the muscles of the thigh. When the thermometer registered 85°C (185°F), the half chicken was removed from the oven and the accuracy of placing the thermometer bulb tested by raising and lowering the thermometer slightly. If the temperature dropped when the thermometer was moved, the half chicken was replaced in the oven and cooking continued until 85°C was again attained. The cooking losses and edible meat are based on the weight of the uncooked half of chicken. The results for 12 roasters are tabulated.

OVEN TEMPERATURE °C	COOKING TIME min	COOKING LOSSES Total %	Volatile %	Drippings %	EDIBLE MEAT AND SKIN %	EDIBLE MEAT ONLY %
125	148.1	18.6	11.4	6.3	61.8	53.5
175	60.6	18.2	10.8	6.4	61.6	53.8

The cooking time at the lower temperature was more than twice as long as at the higher temperature. This accounts for the cooking losses being as great at the lower as at the higher temperature. The palatability scores are tabulated, the highest possible score for each factor being 7.

OVEN TEMPERATURE °C	FLAVOR		TENDERNESS		JUICINESS	
	BREAST	THIGH	BREAST	THIGH	BREAST	THIGH
125	4.6	5.0	6.1	5.5	3.9	5.1
175	5.0	4.8	6.1	5.4	4.6	5.1

The results were not analyzed statistically, but the differences are probably not significant, with the possible exception of the juiciness of the breast meat.

Covered vs. uncovered pans. Halves of 22 roasters (137) were cooked covered, the other halves uncovered, at a constant temperature of 150°C until the interior temperature of the thigh reached 85°C. The cooking time was approximately twice as long for the uncovered (122.0 and 57.3

minutes) as for the covered halves. Covering lessens evaporation; thus with less evaporation a higher temperature is reached in the uncovered pan, since evaporation requires heat. In addition in the covered pan the steam is retained to a greater extent, and this moist atmosphere is a better conductor of heat than dry air. The cooking losses are tabulated herewith.

	Total %	Volatile %	Drippings %
Covered	14.5	8.4	6.3
Uncovered	22.6	20.1	2.2

The scores showed that in aroma, flavor, and juiciness the breast of the uncovered halves was more desirable than that of the covered halves. For the thigh no preference was shown for either the covered or uncovered halves.

Covering the halves of chickens for the last 20 minutes of the cooking period shortened the cooking time, decreased the cooking losses, and increased the tenderness and palatability of the skin but not of the meat. The majority of the scores favored the uncovered halves.

Basting. Basting (139) shortens the cooking period but does not appreciably affect the cooking losses. Butter was used for basting. The salt was removed by washing, the butter was then melted, and the curd allowed to settle. The half of chicken was basted before being put in the oven, at the end of 30 minutes, and again at the end of 60 minutes, a total of 20 grams of butter being used. Basting increased the desirability of the lean meat of both thigh and breast.

Breast up or down. No significant differences were shown in tenderness, juiciness, or flavor by cooking one half of 16 roasters breast side up, the other half breast side down, in an open pan at 150°C. However, the results, as determined by shearing force and press fluid as well as scores, were slightly in favor of the breast side down. The probable reason for this is that, in an open pan, the part of the chicken nearest the pan is protected and heats more slowly than the upper portion over which the hot air circulates. Since the thigh and leg muscles have more connective tissue and are tougher than the breast muscles, hence need longer cooking, breast side down seems to be a procedure well adapted to cooking by roasting the tender and less tender muscles of poultry.

Double vs. single cooking periods. A method sometimes advocated for cooking turkey is to roast the bird until about two-thirds done, remove it from the oven, store overnight, then finish cooking the next day. Hanson (116) cooked 12 turkeys, 9–10 pounds drawn weight, without the giblets or neck. In this study 10 turkeys were halved and cooked, one half by the double, the other by the single cooking method. Two whole birds were stuffed and cooked by the double method. For the double cooking period the half turkey was cooked at an oven temperature of 150°C until the thigh temperature registered about 65°C (150°F), then stored in the refrigerator. The second day both halves were cooked until the thigh temperature registered 85°C. For the single cooking period the other half was refrigerated overnight, then cooked in a single period on the second day Paul (116) repeated this study with the same number but heavier (15–16 pounds) turkeys. She also used stuffing in each half turkey (held in place with wax paper) and stored the halves used in the double cooking period overnight at room temperature.

The double cooking method required nearly twice as long as the single period, thus increasing the cooking losses and the amount of fuel consumed but without increasing the palatability. The bacteriological study conducted in connection with the cooking tests showed that the surface of the turkey and the bread stuffing were not sterilized by cooking to 85°C, thus indicating that storage, especially at room temperature, should not be prolonged.

Time of cooking. This varies with the same factors as those listed for meat, *i.e.,* cooking temperature, degree of doneness, size, composition extent of post mortem changes, and initial temperature. Of these the cooking temperature is, of course, important, for it can vary over a wide range. Roasters may vary in size from a 4-pound chicken to a 25-pound turkey, so that size of the roaster influences not only the total time of cooking but also the time per pound. Larger roasters require a longer total time but a shorter time per pound. At constant oven temperature, 150°C (300°F), roasters weighing 4–5 pounds, dressed weight, require about 35 minutes per pound for cooking. If the estimate is based on the stuffed weight, about 30 minutes per pound is necessary. However, considerable variation in cooking time can be expected.

The Poultry and Egg National Board (141) give the following time table for cooking stuffed turkeys.

Ready-to-Cook Weight lb	Oven Temperature		Total Cooking Time hr
	°C	°F	
4–6	160	325	3.0 –3.75
6–8	160	325	3.75–4.5
8–10	160	325	4.0 –4.5
10–12	160	325	4.5 –5.0
12–14	160	325	5.00–5.25
14–16	160	325	5.25–6.0
16–18	160	325	6.0 –6.5
18–20	160	325	6.5 –7.5
20–24	160	325	7.5 –9.0

Stage of doneness. Many homemakers use thermometers for determining when the interior of roasts has reached the desired stage of doneness. The thermometer bulb may be inserted into the center of the thick part of the thigh muscles or into the breast muscles. It is more difficult to insert the thermometer accurately in poultry than in beef and pork oasts. In addition, if the thermometer has a metal part at the top, its veight tends to pull the bulb from the inserted position. The thermometer s easily inserted into the stuffing through the posterior opening into the urkey.

The interior temperature to which the bird should be cooked varies with a) the stage of doneness desired, (*b*) the location of the thermometer, c) the rate of cooking, and (*d*) the method of cooking. Most persons ike poultry well done. For this an interior muscle temperature of 85–90°C 185–195°F) is usually sufficient. If the thermometer is inserted into the stuffing, the muscles are at a higher temperature than the stuffing, owing to heir being on the outside of the stuffing. In addition a dry stuffing will conduct the heat more slowly than a moist stuffing. Hence the stuffing emperature that results in the most desirable cooked muscles may vary greatly. There is a longer distance for the heat to penetrate into the stuffing in a large turkey. Thus the muscles may be sufficiently cooked when the stuffing temperature is from 70° to 85°C.

When a high cooking temperature is used the rate of heating is rapid; hence to coagulate the proteins of the muscle sufficiently a higher interior temperature is needed than when the birds are cooked slowly.

When the birds are cooked covered or in foil, the steam is held around the bird and the collagen is converted to gelatin more rapidly than in dry-heat cookery.

Effect of feed on flavor. Maw (140) found that the kind of cereal (corn, oats, wheat, or barley) affected the distribution of fat in the flesh (muscle with external fat removed). The corn-fed birds had the most fat in the flesh. The feed also affected the flavor.

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MEAT

Records for Cooked Meats

The initial weight, cooked weight, the total, volatile, and drippings losses in grams, and time of cooking are recorded for each sample of meat. If the volume shrink as well as the weight loss is to be determined, the volume can be taken in cubic centimeters by water displacement, the water being heated so as not to cool the meat. In addition the temperature record is kept. The interior temperature of the meat, the oven, or water temperatures are read and recorded at intervals of 15, 20, or 30 minutes, or as desired. A tracing may also be made of the cut surface of roasts, steaks, and chops. A piece of parchment paper is laid over the cut surface and the entire surface rubbed lightly with the finger tips to bring it in contact with the meat. The fat leaves the paper semi-transparent, and the moisture from the lean portion slightly puckers the paper. A pencil tracing is made around the edge of the meat and the fat and bone areas. A tracing of this sort is better than a photograph since the dimensions are actual size. The definiteness of the distribution of fat, lean, and bone depends on the care of the person making the tracing. A good grade of thin typewriter paper is satisfactory for making these tracings.

Notes or comments on color and cooking performance are recorded as well as the unique characteristics of a particular sample. The results of subjective and objective tests, *e.g.,* score for palatability, *p*H, pounds for shearing, and press fluid, are also recorded.

Beef Roasts

Experiment 22.

To determine the effect on beef roasts of cooking by searing and constant oven temperatures and to different stages of doneness.

The standard roast cooked by the Cooperators of Meat Investigations (123) is the prime three-rib roast consisting of ribs 9–10–11. The twelfth rib is used for chemical or other tests. Ribs 6–7–8 may also be used for class work, which will provide two pairs of roasts from one animal. But for class work it is satisfactory and cheaper to use three pairs of two-rib roasts from one carcass, the pairs consisting of ribs 11–12, 9–10, and 7–8. These pairs may be used to compare cooking losses, exterior and interior color, juiciness, tenderness, and flavor of roasts cooked to different stages of doneness or at various oven temperatures.

Preparation. Weigh the roast. Wipe with a damp cloth. A tracing may be made of the cut surfaces of the meat. Determine the place and depth for insertion of the thermometer bulb. The insertion is started midway of the width of the roast. See Fig. 40. The distance to insert the thermometer should be the diameter of a circle, so that the bulb of the thermometer can be inserted equally distant from the top, the chine bone, and the bottom of the roast. If the depth on one cut surface is 4 inches and on the other 4½ inches, use an average of these two, or 4¼ inches, for the distance represented by the diameter of the circle. Measure up from the center of the thermometer bulb 2⅛ inches on the stem and insert to this depth in the roast. The incision for the thermometer should be made with a very narrow knife blade, about ¼ inch in width, or a skewer, so that the meat will fit tightly around the thermometer. For a rolled roast find the radius (one-half of the diameter) and insert the center of the thermometer bulb to this depth in the middle between the two ends of the roast.

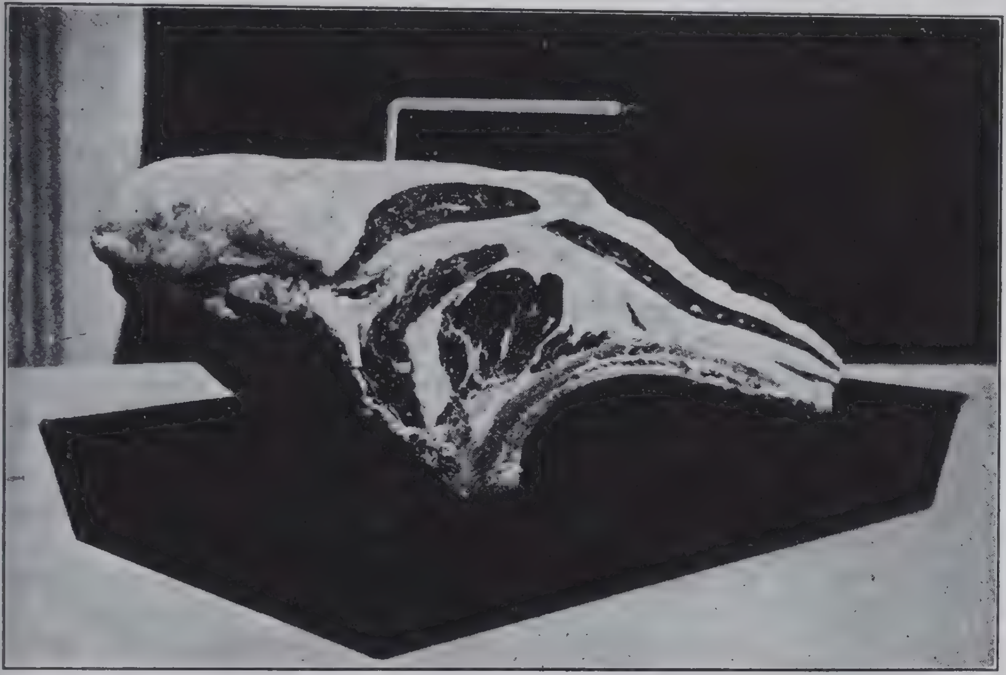

FIG. 40. Standing rib roast of beef, showing thermometer inserted for reading interior temperature of the meat.

Weigh the thermometer and the cooking pan. Use an open pan; a common, sheet-iron pan is suitable. The pan may be lined with aluminum foil, the foil being weighed with the pan, to facilitate washing the pan. Use as small a pan as possible so the drippings will not spread over a large area. A standing rib roast rests on the chine bone and rib ends, which keeps the roast above the drippings. See Fig. 40. A rolled roast is laid on a rack with the fat side up. No water or seasoning is added. Record the inner temperature of the roast and oven at definite intervals, 10, 15, or 20 minutes, during the cooking period.

A. Cook one roast of a pair (A1) by the searing method, the other (A2) by the constant-temperature method.

Searing method. For experimental comparisons sear the roast for 20 minutes at 250°–275°C (about 480–525°F) and transfer at the end of 20 minutes to a second oven at 125°C (about 255°F). For a searing method for the home, sear at 220°C (about 425°F) for 20 minutes, then set regulator at 125°C.

Constant-temperature method. Place the roast in an oven at 150°C (about 300°F).

Cook the roast until the thermometer registers 63°C (145°F), recording the temperature at regular intervals for graphs. (For Cooperative Meat Investigations the roasts are cooked to an interior temperature of 58°C [about 137°F].) For two-rib roasts from a pair of prime ribs weighing 42–50 pounds allow 140–150 minutes for cooking, though the time will vary. If the roasts are very chunky or the interior temperature at the start is very low allow a longer time. If the roasts are thin and long, allow a shorter time. Add another 25–30 minutes for the temperature rise after removal from the oven. Record the temperature rise after removal from the oven every 5 minutes until two readings are the same or the temperature begins to fall. Weigh the roast. Weigh the pan and drippings.

If the volatile and drippings losses in the oven are to be determined separately from those after removal from the oven, the roast is weighed at the time it is removed from the oven and transferred to a weighed platter. When the maximum interior temperature is reached, the roast is reweighed to determine the volatile loss during the interval after removal from the oven and attainment of maximum interior temperature. The platter is reweighed to determine the drippings collected outside the oven.

To determine the amount of fat in the drippings transfer the drippings carefully to a graduate of suitable size. Keep warm until the fat has risen to the top. Then read the number of milliliters of fat and aqueous drippings.

Measure the width of the roast and compute the shrinkage in width during cooking. Note the exterior appearance, whether the main muscle (the longissimus dorsi) bulges outward, is straight, or is concave. Note the shrink along the rib ends. If a copy is attainable compare with the illustrations in "A precise method of roasting beef," by Sprague and Grindley (133). If a standing rib roast is used, remove the ribs and chine bone. Then cut the roast through the center. Describe the interior condition, color, uniformity of color throughout the roast, its sheen, and the amount of juice on the surface of the lean. Are all the muscles the same color?

Samples for scoring. Since the roast has been cut through the center for observation of its interior, start slicing the samples for scoring from the center, discarding the exterior brown slices. Slice as many samples as there are people for scoring. Be sure that each person receives the corresponding slice from each roast; *i.e.*, scorer A gets the center slice from each roast, B the one next the center, etc. If slices are very large, and there are several students, the slices may be divided, but again in dividing be sure that each scorer gets the same anatomical samples, *i.e.*, from the same slice and from the portion nearest the chine bone or from the rib end. Score for tenderness, flavor of lean and fat, and juiciness.

Determine the percentage lost during cooking, the dripping loss and the volatile loss. Plot on graph paper the rise in inner temperature of the roast, during cooking and after removal from the oven. The weight of the bones and the per cent edible may also be determined. Calculate the time per pound required for cooking.

B. Cook one roast of a pair (B1) in a constant oven temperature, 150°C, until the interior of the roast reaches 55°C (about 130°F). Cook the other (B2) until the interior temperature reaches 75°C (about 165°F). Allow about 100 minutes for cooking B1 and about 170 minutes for B2, though the time will vary.

Follow directions under A.

Experiment 23.

To compare the rate of temperature rise near the surface and the interior of the roast, and through lean and fat.

Repeat Experiment 22, A2, but place a second thermometer ½ inch from the cut lean surface. If the roast has a deep fat covering, place a third thermometer bulb in the fat ½ inch from the surface. For economy, these tests may be combined with Experiment 22, A. Plot on graph paper the temperature rise in different portions of the roast.

Experiment 24.

To determine the effect of cooking at different temperatures on cooking time, cooking losses, and palatability of beef rib roasts.

Use paired roasts. Follow directions under 22, A. Cook the roasts to the same interior temperature, 63°C. (If desired, either 55° or 75°C may be used.) Allow about 120 minutes at 200°C and about 210 minutes at 125°C, though the time will vary.

1. Use a constant oven temperature of 125°C (about 255°F) for one roast of the pair.
2. Cook the other roast at a constant temperature, 200°C (about 400°F).

If rolled instead of standing rib roasts are used, they should be placed on racks to keep them above the drippings. Compute losses and make records as suggested under Experiment 22.

What is the interior temperature of a roast which is rare? Of a medium well-done roast? Of a well-done roast? In each case what was the number of minutes per pound required for roasting? What is the effect of increasing the size of the roast on the time required per pound? How much did the inner temperature of roasts rise after removal from the oven? What factors cause variations in this rise in temperature? If a rare roast is to be served immediately, at what temperature would you remove it from the oven? Is the rate of increase of inner temperature of the different roasts constant?

Lamb, Pork, and Veal Roasts

Experiment 25.

To determine the effect on roasts of cooking at different temperatures.

Use roasts of lamb, pork, and veal, but if possible the roasts should be paired; that is, use the same cuts from the right and left sides of the same carcass. Make tracings of cut surfaces of the roasts. Record the total time for cooking. Follow directions for records and scoring under Experiment 22, A.

A. Lamb.

Preparation. Weigh the roast. Wipe with a damp cloth. Insert the thermometer bulb into the thickest portion of the leg. To determine the depth of insertion, hold two rulers at right angles to each other and insert the center of the thermometer bulb to one-half the depth on the vertical ruler. A leg of lamb is placed on a rack in an open pan, skin or fell side down. (The fell may be removed, but Alexander and Clark [120] found that its removal increases the cooking losses and the cooking time without increasing the palatability of the meat.) Standard cooking temperatures are the same as those for beef, *i.e.,* 150°C constant oven temperature or sear for 250°C for 20 minutes then cook at 125°C.

1. Use a constant oven temperature of 150°C (about 300°F). Cook to an interior temperature of 75°C (about 165°F). Do not remove the fell.

2. Repeat 1, but remove the fell from this leg of the pair. Do your results check those of Alexander and Clark (120)? Allow about 180 minutes for cooking a 5-pound leg of lamb, though the time will vary.

Any of the tests listed under Experiments 22 and 24 may be repeated using lamb leg roasts.

B. Pork loin.

The standard cut for the Cooperative Meat Investigations is the center cut of pork loin which includes the last four dorsal and the first four lumbar vertebrae. It is cooked at 175°C to an interior temperature of 84°C.

For class work paired loin roasts cut 4 inches wide, excluding the 4 inches at either end of the loin, are excellent for comparisons and less expensive than the larger roast.

Preparation. Weigh the roasts. Insert the thermometer in the same manner as for beef rib roasts. Place the roast with fat side up on a rack in a weighed pan. Follow directions under Experiment 22 A, for records.

1. Compare searing at 250°C (about 480°F) for 20 minutes and then transferring to a 150°C oven with cooking at a constant oven temperature of 150°C (about 300°F).

2. Compare an oven temperature of 150°C with a 175°C (about 350°F) oven.

C. Veal.

The standard veal cut for the Cooperative Meat Investigations is the thigh section cut through the femur joint inside the enlarged joint. The length of bone is 3 to 4 inches. It is cooked at a constant oven temperature of 150°C (about 300°F) to an interior temperature of 71°C (about 160°F).

For class comparison loin roasts of veal are satisfactory. They are cooked on a rack in an open pan. Follow the directions under Experiment 22 A, for recording data.

Use the temperatures suggested under Experiments 22 and 24 to determine the effects of cooking temperature on palatability.

Allow about 100 minutes for loin roasts cooked at 150°C, although the time will vary. If desired the veal may be cooked to 83°C (about 180°F) interior temperature. The research kitchen of Swift's prefers 83°C to 71°C.

Experiment 26.

To determine the effect on roasts of lamb, pork, and veal of cooking to different stages of doneness.

Cook lamb and veal by the constant-temperature method at 150°C, the pork at 175°C. Follow the directions under Experiment 22 A, for recording data. Vary the interior temperature to which the roasts are cooked as follows:

Lamb: 71°, 75–76°, and 83°C (160°, 167–169°, 181°F).
Pork: 80°, 85°, and 90°C (about 175°, 185°, and 195°F).
Veal: 71°, 75°, and 80°C (160°, 167°, and 176°F).

Steaks and Chops

Experiment 27.

Steaks.

To determine the effect upon steaks of cooking by different methods and to different interior temperatures.

Steaks for comparative tests used by the Cooperative Meat Investigations are cut 2 inches thick. The cuts used are: *rib steaks,* the twelfth rib; *porterhouse,* the first cut from the short loin, next to the loin end; *sirloin,* the first cut from the loin end, next the rump; and *round,* the first cut from the round, next the rump.

For class work steaks 1 to 1¼ inches thick are satisfactory. They have the advantage of being used more frequently than the 2-inch steaks. It is also advisable to work out methods of cooking for the commonly used ½-inch steaks.

Preparation. Weigh the steak. Make a tracing of the cut surfaces. Measure the thickness. Insert a weighed thermometer, so that the bulb is midway, *i.e.,* ½ inch from the top and from the bottom of a 1-inch steak. A right-angle thermometer is preferable for steaks to be pan-broiled, but either a tube or right angle may be used for broiled steaks. Steaks may be turned at regular intervals or only once. If turned only once, Cline suggests turning when about three-fifths of the expected temperature rise has occurred. If the temperature of the steak is 10° and it is to be cooked to an interior temperature of 60°, the temperature rise will be 50°, and three-fifths of 50 equals 30. Thus the steak will be turned when the inner temperature is about 40°C. To turn, stick a fork into the flank muscle, connective tissue, or firm fat, not into one of the principal muscles.

Keep a record of the interior temperature of the steaks at regular intervals. After removal of the steak from the oven or pan, note and record the rise of interior temperature every half minute until the temperature is constant or starts to drop. Then weigh the steak. Record the time for cooking and minutes seared on each side (if searing is used). Compute the total, the volatile, and drippings losses. Plot on graph paper the temperature rise during and after cooking.

Compare the steaks for exterior appearance, interior color, juiciness, flavor, and tenderness. In preparing samples for testing, be sure the scorer gets the same slice from each steak.

A. Temperature and method of cooking.

1. *Broiled.* Weigh the broiling pan and rack. Place pan so that the top of the steak will be about 3 inches below the flame. A griddle or other thermometer, mounted to be extensible, is placed at the right front on the first two rods after adjusting the bulb of the thermometer so that it will be the same height as the top of the steak. If the broiler door can be left open it is more convenient to cook the steak with the door open, as the temperature can be regulated more readily. Adjust the regulator and heat the broiler pan and rack until the thermometer registers the desired temperature. If necessary turn the indicator to its highest temperature, then regulate the flame by the

volume of gas flow, *i.e.,* the extent to which the cock is turned. Place steak on the rods in the center of the pan with the meat thermometer at the right-hand side, and broil until the temperature for turning is reached. Turn steak so that the meat thermometer is still at the right, and turn reading scale up. For a lower cooking temperature the broiler pan can be moved farther from the flame; for a higher one, nearer. Also the length of the flame may be regulated to alter the temperature.

Cook to an interior temperature of 61°C (about 140°F).

Use any or all of the following temperatures: (*a*) a constant temperature of 150°C (about 300°F); (*b*) 175°C (about 350°F); (*c*) 200°C (about 390°F); and (*d*) with regulator set at "broiling."

For searing the following procedure may be used: (*e*) sear on each side for 2 minutes at 225°C (about 435°F), then lower the flame or the broiling pan to adjust the temperature to 125°C (about 255°F); or (*f*) after searing lower the temperature to 150°C (about 300°F).

2. *Pan broiled.* Prepare the steak as for broiling in the oven. Use a heavy metal skillet, and adjust so that it is heated uniformly and not too rapidly. Place a griddle thermometer on the bottom of the skillet and heat until the desired temperature is reached and maintained before the steak is placed in the skillet. For experimental purposes, if the steak is to be seared use two skillets and transfer to the second skillet after searing. If the temperature is uniform the griddle thermometer may be removed when the steak is added, or if there is room it may be placed at the side of the steak. Place the steak in the pan with the reading scale side of the thermometer up. If the steak is soft it may need to be held or supported. Follow directions under oven broiling for turning and cooking.

Use any or all of the following constant temperatures: (*a*) 150°C, (*b*) 175°C, and (*c*) 200°C.

For searing use any or all of the combinations which follow: (*d*) sear 1 minute on each side at 200°C (about 390°F), then transfer to a skillet at 125°C (about 255°F); (*e*) sear at 200°C, and transfer to 150°C; (*f*) sear at 250°C (about 480°F), and transfer to 125°C; and (*g*) sear at 250°C, and transfer to 150°C.

B. Varying the interior temperature to which the steak is cooked.

1. Use the same method for cooking all steaks. Follow directions under 27 A, and cook until the interior temperature reaches 55–57°C (about 130–135°F).

2. Repeat 1, but cook medium well done, 61°C (about 140°F).

3. Repeat 1, but cook well done, 71°C (about 160°F).

C. Thickness of the steak.

Cook by the same method and to the interior temperature decided upon by the class. Compare the cooking losses and time of cooking.

1. Use a steak ½ inch thick (it may not be possible to use thermometer).

2. Repeat 1, but use a 1-inch-thick steak.

3. Repeat 1, but use a steak cut 1½ inches thick.

Chops.

Use chops of lamb, veal, or pork. Any of the experiments under steaks may be repeated, cooking lamb to an interior temperature of 75°C (about 165°F), veal to 71°C (about 160°F) or 83°C (about 180°F), and pork to 84°C (about 185°F).

The chops may be broiled or pan broiled.

1. Broil at constant temperatures of 125°C, 150°C, 175°C, and 200°C.
2. Sear at 225°C (about 435°F), and cook at 150°C (about 300°F), or sear at 200°C (about 390°F), and cook at 175°C (about 350°F).
3. Pork chops may be cooked covered or uncovered, using a searing temperature and then cooking by adding a small portion of water and braising.

Less Tender Cuts

Experiment 28.

To determine the effect of various factors in cooking less tender cuts of meat.

Braising. Braising is cooking with a small amount of moisture at a low temperature, the meat having previously been seared or not, as desired. For home use a better browned appearance is obtained if less water is added for each addition than indicated for the experimental tests below. Use paired cuts. Cuts from the neck, flank, rump, round, or particular muscles from the round such as the semitendinosus may be used. One piece is cut from the right, and a second piece of the same size from the same position from the left side of the carcass. Pieces weighing about 1 to 1½ pounds are satisfactory for class work.

Preparation. Weigh the pieces. Each member of the class cooks a pair of cuts. Everything, as nearly as possible, should be standardized, except the variable being tested. For example, if the effect of pounding it to be determined, both pieces may be seared but only one should be pounded.

Add 2 grams of salt per pound of meat. Add ¼ cup of liquid per pound and more if necessary, but keep a record of the amount added. With larger pieces of meat a relatively smaller proportion of liquid may be added. If necessary to add water, have it boiling.

Cooking temperatures. If the meat is to be seared, place a griddle thermometer on the bottom of the container and heat to 150°C (about 300°F), and for sufficient time to know that the temperature is constant. Sear the upper and lower cut surfaces 5 minutes on each side. At the end of 10 minutes place a rack under the meat, and add the water or other liquid. Insert a short tube or a right-angle thermometer into the center of the thickest portion of the cut. Place a griddle thermometer on the rack beside the meat, and adjust heat to maintain the temperature at 85–88°C (about 185–190°F). If griddle or other thermometers are not available, greater uniformity of cooking by the class may be obtained by letting the liquid boil slowly.

Cook to an interior temperature decided upon by the class, 85°C (185°F) or 95°C (about 200°F). If the latter temperature is used, the temperature inside the container will need to be raised to boiling, at least for the latter part of the cooking period.

Use covered containers, of a size suitable for the pieces of meat being cooked, such as casseroles, Dutch ovens, or skillets. For some experiments both pieces of the pair may be cooked in the same container, one or both pieces being marked with a metal tag or with toothpicks. For other tests separate utensils will be needed for each piece of meat.

Determine only the total cooking losses. Compare the juiciness, flavor, tenderness, and sliceability of the meat.

The following suggestions are offered for tests:

1. Pounded vs. not pounded.
2. Floured vs. not floured (neither piece pounded).
3. Floured vs. not floured (both pieces pounded).
4. Seared vs. not seared (neither pounded nor floured).
5. Seared vs. not seared (both pounded and floured).
6. Covered vs. uncovered.
7. Lower (simmer) vs. higher temperature (boiling over flame).
8. Lower vs. higher temperature (in oven).
9. Add tomato juice as liquid to one piece, an equal quantity of water to the other.
10. Repeat 9 but substitute sour cream for the tomato juice.
11. Remove one piece when the interior temperature reaches 75°C, the other when the inner temperature reaches 85°C.
12. Remove one piece when the interior temperature reaches 85°C, the other at 95°C.

Many combinations of the above suggestions and other combinations not mentioned may be tried.

Cooking Meat in Water

Experiment 29.

To determine the effect of temperature of the water upon the palatability of the meat.

Stews. Use neck, heel of round, or any of the less tender cuts. Cut the meat into cubes of the size desired, using equal quantities from each side of the carcass. Wrap the cuts from the left side of the carcass in one package, those from the right side in another. Label so that identity will be known. Cook this pair for comparisons. Cook in covered utensils. The amount of water added is usually just sufficient to cover the meat. This will have to be determined in connection with the utensils used for the stew. At the start try using ½ cup of liquid to each pound of meat. For boiling temperatures this should be doubled. Use 2 grams of salt per pound of meat. For stews the meat is usually prepared in one or three ways. (*a*) Brown stew. The meat is seasoned and seared in fat before it is added to the boiling liquid. The meat may be floured before it is seared. The flour browns more readily and adds color to the liquid. (*b*) The meat is added directly without searing to the boiling liquid. (*c*) The meat, without being seared, is added to the cold liquid and heated slowly to the desired temperature. If vegetables are used with the stew, they are added so that they will just become tender before the stew is served. The broth of the stew may be thickened slightly.

1. Brown stew. Keep cubes from the left and right sides separate. Dredge meat cubes with flour. Add salt. Sear in hot fat. Cook cubes from one side at simmering temperature 85–90°C (185–195°F) temperature, the other in boiling water. Put browned cubes in respective containers of heated water. Add water (at cooking temperature for each stew) as needed, but the amount of broth when served should not cover the meat or the meat and vegetables. It will take more than twice as long to cook the cubes at simmering than at boiling temperature.

2. Repeat 1, but add the unseared meat to the boiling water.

3. Repeat 1, but add the unseared meat to cold water. Heat slowly to simmering and boiling temperatures.

Compare the meat from the various stews for flavor, juiciness, sliceability (if pieces are large enough to slice), stringiness, tenderness, and time of cooking.

Broth

Experiment 30.

To determine the best method of making broth.

Use ½ pound of meat and 1 pint of water for each experiment. Add water as necessary to keep the volume constant.

1. Cook the meat in one piece. Start in cold water and heat to 85°C. Cook until tender, keeping the temperature 85°C.
2. Repeat 1, but cut the meat in 1-inch cubes.
3. Repeat 1, but grind the meat.
4. Repeat 2, but start in boiling water and cook at boiling temperature.
5. Repeat 2, but sear the meat before adding to the water. What are the differences in the broth in each case? How is a clear broth prepared? Strain some of the above broths. To another add a beaten egg white, heat, then strain.

Ground Meat

Experiment 31.

To determine the effect of various factors upon the palatability of ground meat.

Meat loaf.

Recipe:

Ground lean beef	¼ pound	113 grams	Ground suet	14 grams
Butter	½ tablespoon	7 grams	Bread crumbs	25 grams
Egg, beaten	¼	12 grams	Pepper	1/16 teaspoon
Milk	¼ cup	61 grams		
Salt	¼ teaspoon	1 gram		

Mix the ingredients lightly with a fork. The meat loaf may be baked in individual casseroles or in beakers. The bulb of a right-angle thermometer may be placed in the center of the loaf, the thermometer being suspended by the horizontal arm on a rack above the meat. A short tubular thermometer, 6–8 inches long, is better than the right-angle one, for it needs no rack above it to keep it adjusted in the loaf. Ground meat from the retail market may be used for A and B and the suet omitted.

A. The temperature to which the meat loaf is cooked.

1. Bake in an oven at 160°C (about 325°F) until the interior temperature reaches 75°C.
2. Repeat 1, but remove from the oven at 80°C.
3. Repeat 1, but remove from the oven at 85°C.
4. Repeat 1, but remove from the over at 90°C.

B. The temperature of the oven.

Bake to the interior temperature found best under A.

1. Bake at 150°C (about 300°F).
2. Bake at 160°C (about 325°F).

3. Bake at 175°C (about 350°F).
4. Bake at 185°C (about 365°F).

C. Effect of fineness of grinding of the meat.

Bake to interior and oven temperatures found best under A and B.

1. Grind meat once, using a coarse knife in the grinder.
2. Grind meat once with a medium knife.
3. Grind meat once with a fine knife.
4. Repeat 2, putting meat through the grinder 4 times.
5. Repeat 3, putting meat through the grinder 4 times.

D. The effect of increasing the fat.

Bake to interior and oven temperatures found best under A and B. Grind to the degree of fineness found best under C.

1. Add 7 grams of ground suet. (If desired butter may be substituted for the suet.)
2. Add 14 grams of ground suet.
3. Add 21 grams of ground suet.
4. Add 28 grams of ground suet.

Compare the flavor, moistness, and texture of the various meat loaves.

Hamburger.

Recipe:

Ground beef	¼ pound	113 grams
Egg	¼	12 grams
Salt	¼ teaspoon	1 gram
Pepper	1/16 teaspoon	

Mix the ingredients together with a fork. For uniformity of temperature the hamburger may be baked in custard cups according to directions given under meat loaf. It may also be made into patties and seared, then cooked slowly as is the usual practice.

1. Repeat section A under meat loaf.
2. Repeat section C under meat loaf.

Cured Meats

Ham

Experiment 32.

To determine the effect of various factors affecting the palatability of ham.

Hams may be secured with a light or a heavy salt cure. The former do not need to be soaked before cooking; the latter may be improved by soaking.

Preparation. For hams with a light salt cure, scrub with a brush. Dry, then weigh. Insert thermometer so that the center of the bulb is at the center of the thickest portion of the ham, with rind or fat side up. To determine the depth for inserting the thermometer use two rulers at right angles to each other. Or with a steel skewer pierce the rind or fat side, running the skewer point just through the ham. Withdraw and measure the depth the skewer was in the ham. The thermometer is to be inserted half this distance. If the rind has not been removed, it will need to be cut away with scissors or a knife so that the thermometer can be inserted. Use hams of about the same weight for all the tests.

For hams with a heavy salt cure, soak, keeping the time of soaking and the amount of water used standardized. Soak overnight using a quart of water to each pound of ham. Remove from the soaking water and drain 10 minutes. Weigh and proceed as for non-soaked hams.

Record the temperature of ham and oven every 10 minutes for the first 30 minutes, then every 20 or 30 minutes. If the rind has not been removed previously, remove after the ham comes from the oven. If to be scored hot, cut as soon as the maximum temperature is reached. If to be scored cold, store after removing rind.

A. Baked ham.

Place the ham fat side up on a rack in an open weighed pan. Add no water or seasoning.

1. Bake in an oven at 125°C (about 255°F) until an interior temperature of 70°C is reached.
2. Repeat 1, but cook to an interior temperature of 75°C.
3. Repeat 2, but cook to an interior temperature of 80°C.
4. Repeat 1, but have the oven temperature 150°C (about 300°F).

B. Boiled ham.

Use kettles with covers, ham boilers, or boilers of such size that the water will cover the ham. The ham is placed on a rack, rind or fat side up. Use an ordinary laboratory thermometer to take the temperature of the water. Add 1 quart of water per pound of ham. Occasionally add water at the same temperature as water in which ham is cooked to replace that lost by evaporation.

1. Let simmer in water at 83°C until an inner temperature of 75°C is reached. Or, if preferred, use the interior temperature preferred with baked ham. Remove from the water. Drain. Weigh. Keep overnight in the refrigerator.
2. Repeat 1, but let the ham cool overnight in the liquor in which it was cooked. Let the kettle remain in the room so that the liquid will cool to room temperature. Remove from the liquid. Drain 10 minutes and weigh. Place in the refrigerator to be scored with hams from 1 and 3.
3. Repeat 1, but put the kettle or boiler in the refrigerator overnight, letting the ham cool in the liquor in which it was cooked. Remove from liquid. Drain 10 minutes, and then weigh.
4. Repeat 1, but keep the temperature of the water at 87°C.
5. Repeat 1, but keep the water at 78°C.

CHAPTER

9

Emulsions

When one liquid is dispersed in small droplets in a second liquid with which it is immiscible the product is called an emulsion. The dispersed droplets are not uniform, their diameters varying in size. In most emulsions the dimension of the dispersed droplets is greater than 0.5 μ. However, the stabilizing film may have colloidal dimensions. The term liquid is used loosely in food emulsions and seldom refers to a pure substance. In emulsions one liquid is known as water, the other as oil. The phase called water may contain proteins, salts, and other substances. Likewise oil may contain other fat compounds or fat-soluble substances, in addition to the simple triglycerides. Milk is a natural emulsion and a good illustration of the two phases containing other substances in addition to water and oil. The fat globules of milk and cream are stabilized to a considerable degree by the phospholipids. But casein, albumin, globulin, and the milk salts also play a role in the stabilization. Sometimes, as in egg yolk, the water phase may also contain fat. There are many excellent references on emulsions. For beginning reading the book by Sutheim (40) is suggested. Food emulsions are considered herein, but, if the reader is curious about other types, Bennet (4) lists 963 emulsions.

Classes and Types of Emulsions

Emulsions are classified as dilute or concentrated. In the dilute class, which is known as a hydrosol, only the oil-in-water types are known, and for a permanent emulsion the proportion of oil is very small, usually less than 1 part in 10,000 parts of water. These emulsions are of little importance in food preparation. The concentrated emulsions may be either of two types according to whether the water or the oil is the dispersed phase, *i.e.,* water-in-oil (W/O) or oil-in-water (O/W). To obtain a stable and permanent concentrated emulsion a third substance, known as an emulsifier or emulsifying agent, is necessary.

The Theory of Emulsification

Many theories have been advanced for the way in which the emulsifier stabilizes the emulsion. These theories to 1935 are summarized by Clayton

(10). Some of the theories are very similar. The most accepted theory at present is often called the adsorbed film and/or interfacial tension theory.

Adsorbed film and interfacial tension theory. Bancroft (1, 2) stated the underlying principles for this theory, basing them upon the work of Gibbs and the early work on interfacial tension by Donnan. The emulsifier is positively adsorbed more by the dispersing medium than by the dispersed phase. The adsorption of the emulsifier at the interface lowers the surface tension of the dispersing medium more than that of the dispersed droplets. With lowering of the surface tension the dispersing medium has less tendency to form drops, flows to form a film readily, and becomes the continuous phase. The emulsifier must lower the interfacial tension more on the side of the continuous phase than on the side of the dispersed phase. If the surface tension is the same on both sides of the emulsifying film, no emulsion is formed. Berkman and Egloff (5) state that the interfacial tension, acting as a contractile force, draws one of the components of an emulsion system into a series of spherical droplets.

Later references are more apt to speak of emulsification in terms of polar and non-polar groups. The most stable emulsifiers have both strong polar and non-polar groups, but one group must be slightly dominant. If the polar group is dominant it is adsorbed more strongly in the water than in the oil phase and thus lowers the surface tension of the water, so that water becomes the continuous phase. However, the non-polar groups, such as a hydrocarbon chain or a benzene ring, may be partially adsorbed in the oil phase. Thus the emulsifier can be likened to a film lying between the two phases of the emulsion, with polar groups lying in the water and non-polar groups in the oil surface. The emulsifier is not like a film that can be punctured for it is made up of many molecules.

Emulsification is easier if the interfacial tension is low. Harkins and Zollman (22) observed that with an interfacial tension below 10 dynes per cm the benzene emulsified easily in the aqueous phase, but with interfacial tension below 1 dyne per cm emulsification appeared to be spontaneous.

Denaturation. Some proteins, such as egg albumin may become denatured in the surface layer. An early reference to this is cited by Clayton (10): as early as 1840, Ascherson observed "that coagulation in form of a membrane occurs inevitably and instantaneously when albumin comes into contact with a liquid fat." Thus Ascherson observed that proteins are denatured at surfaces and form stable emulsifying films, although his observations were not explained in these terms.

Peptization. The behavior of emulsions is often unpredictable, but anyone who has observed the ease with which large quantities of oil can be emulsified in a much larger quantity of stable mayonnaise by stirring occasionally with a fork or spoon has a strong conviction that the oil is being divided by the emulsifier, whether this mechanism is by peptization or other means. However, peptization is a possibility. Gortner (18) states, "Possibly emulsions could be classified as a fifth group of colloidal systems formed by peptization." Concerning peptization Bancroft (2) says that it is always due to adsorption, for the adsorbed substance tends to "scrunch up" and to peptize the adsorbent. "There will be no visible effect if the work necessary to disintegrate the adsorbent is greater than can be accomplished by lowering of the surface tension."

The Type of Emulsion Formed

The type of emulsion formed, *i.e.,* O/W or W/O, depends upon several factors, among which are (*a*) the nature of the emulsifying agent; (*b*) the presence of electrolytes, their concentration, and kind; (*c*) the nature of the oil; (*d*) the order of incorporating the oil or water; and (*e*) the proportion of oil and water.

In general, hydrophilic emulsifiers favor the formation of O/W, whereas hydrophobic ones favor the W/O types of emulsions. The potassium and sodium soaps are more soluble in water than in oil and tend to form O/W emulsions. Magnesium and calcium soaps are more soluble in oil than in water and may form W/O emulsions. If potassium and sodium soaps are used and calcium and magnesium are added, as may happen in very hard water, the emulsion may be reversed. Iron soaps are strongly hydrophobic and form W/O emulsions. King (28) designates the soaps as colloidal electrolytes and finds that their concentration also affects the type of emulsion formed. For example, certain concentrations of sodium oleate formed O/W emulsions, whereas less than this amount gave the opposite type.

Seifriz (36), in his work with petroleum emulsions stabilized with casein solution, found that the oils with specific gravity of 0.828 or below form oil-in-water emulsions. When the specific gravity of the oil is greater than 0.857 a water-in-oil emulsion is formed, and oils with specific gravity between 0.828 and 0.857 give coarse, unstable emulsions or cannot be emulsified. Bancroft (2) comments that it is not the specific gravity *per se* which determines the types of emulsion formed. One of his suggestions is that petroleum oils of higher specific gravity peptize casein more readily than water.

Seifriz (36) has reported that "olive oil stabilized with sodium oleate, sodium stearate, gelatose, gum arabic, albumin, lecithin, saponin, senegin, smilacin, or plant juices (cell sap and protoplasm) forms oil-in-water emulsions, while the same oil stabilized with casein, gliadin, cholesterin, or cephalin forms water-in-oil emulsions. In addition with casein as the emulsifier the following oils all give water-in-oil emulsions: olive, castor bean, poppy seed, sperm, and cod-liver oil. Linseed oil forms with casein a dual emulsion with the water-in-oil type predominating. Lecithin favors the formation of oil-in-water emulsions, whereas cholesterol favors water-in-oil emulsions."

Cheeseman and King (8), in what they call "dual" emulsions, *i.e.,* using he same two immiscible liquids and the same emulsifier, have shown that either a water-in-oil or oil-in-water emulsion may be formed, depending upon the method of shaking. With some substances the type of emulsion formed depends upon which phase is gradually added to the water.

The phase-volume theory (10) is no longer tenable but by this theory one type of emulsion was formed until 74% of one phase was dispersed in the other. With addition of more of the dispersed phase than 74% the emulsion is supposed to reverse.

Means of determining the type of emulsion. An O/W emulsion conducts an electrical current readily; a W/O does not.

The drop-dilution method is often used to determine which is the continuous phase and which the dispersed phase. A drop of the emulsion is placed on a slide, and while it is observed through the microscope a small drop of water is added and stirred with a pin point. If the water blends with the emulsion it is an O/W emulsion. However, if the oil blends with another drop, the outside phase is oil and it is a W/O emulsion.

Another method of determining the type of emulsion is to use Sudan III or Scharlach R, red dyes soluble in the oil but not in the water. A small portion of the finely powdered dye is dusted over the surface of the emulsion. If oil is the external phase the color gradually spreads throughout the emulsion. But if water is the external phase the color does not spread but is confined to the oil with which it comes in contact on the surface.

The microscope may be used to determine the type of emulsion formed. If the oil is dyed red, a red field with clear globules indicates a W/O emulsion; red globules in a clear field show an O/W emulsion. Sometimes a multiple emulsion is obtained, *i.e.,* a dispersed phase within a dispersed phase. The only means of identifying a multiple emulsion is by the microscope.

Emulsifying Agents

Requirements. Sutheim (40) gives the requirements of an emulsifier as follows: It (*a*) must reduce the surface tension, (*b*) stabilize the emulsion, (*c*) must be chemically stable, (*d*) be selective, *i.e.,* form an O/W or W/O emulsion as desired, and (*e*) for food emulsions must be edible and preferably odorless, light in color, and cheap.

The emulsifier reduces the surface tension, and the molecules become oriented, the polar parts being attracted to the water phase, the polar group being pulled into or partially into the water, whereas the non-polar groups will be oriented to the oil phase. If the hydrophilic parts of the molecule are slightly stronger than the hydrophobic portions, more of the molecule will be absorbed by the water phase. This (40) will cause the interfacial film, although very thin, to develop a concave curvature towards the oil phase.

Some emulsifiers used in foods. Egg yolk, whole egg, milk, and starch pastes have roles as emulsifiers in many food products and will be discussed later. Pectin and gelatin may be used as emulsifiers.

Of the many emulsifiers used in industrial, medicinal, and cosmetic emulsions, Bennett (4) lists 601. These include food emulsifiers. Compared with Bennett's list the edible emulsifiers that may be used in foods are limited. The Food and Drug Administration (15*b*) permits the use of one or a mixture of two or more of the following emulsifiers in French dressing: gum acacia (gum arabic), carob-bean gum (locust-bean gum), guar gum, gum karaya, gum tragacanth, extract of Irish moss, pectin, propylene glycol ester of alginic acid, and sodium carbonylmethylcellulose. The following (16) are allowed in bread: lecithin, mono- and diglycerides (except lauric acid), diacetyl tartaric esters of mono- and diglycerides of fat-forming fatty acids (except lauric). The amount permitted is specified. Pasteurized process cheese may contain one or any mixture of two or more of the following emulsifying agents (15*a*): mono-, di-, or trisodium phosphate, sodium metaphosphate, sodium pyrophosphate, tetrasodium pyrophosphate, sodium citrate, potassium citrate, calcium citrate, sodium tartrate, and sodium potassium tartrate. In Neufchâtel cheese the following emulsifiers may be used: gum karaya, gum tragacanth, carob-bean gum, gelatin, and algin. These lists give some of the substances used specifically as emulsifiers.

As indicated in the Food and Drug identity standards, sometimes one or more emulsifiers are used in the same food.

The use of the emulsifier. The tendency in the literature to discuss emulsifiers and stabilizers together is undoubtedly because the same substance is often used for both purposes. Thus gelatin may form an emulsion with oil and stabilize sugar crystals in candy or ice crystals in ice cream, *i.e.,* prevent their growth. As a stabilizer pectin may aid in keeping tomato pulp particles suspended in tomato juice (11), or a gum may keep chocolate from settling in chocolate milk.

During the period from 1940 to 1950 a large number of substances were developed for emulsifiers in food. Many of these substances included certain sorbitan partial esters of fatty acid, polyoxyethylene derivatives of these sorbitan partial esters of fatty acid, and polyoxyethylene derivatives of the fatty acids. There has since been an adverse ruling to the use of these emulsifiers in bread. Pratt (34) discusses the function of the emulsifiers as well as the amount needed in different types of food. His list illustrates the various uses for emulsifiers: in bread to retard hardening of the crumb after baking; in cakes (both fat type and sponge) to allow increase in sugar and water content, resulting in "finer texture, improved lightness, tenderness, and eating quality"; in ice cream to promote finer division of fat globules and air cells; and in candies. The use in candies is varied. The emulsifier may control fat bloom in chocolate coatings and act as a stabilizer to give smaller sugar crystals. In chewy caramels emulsifiers are said to lessen sticking to the teeth and wrapper. Other uses are to give more uniform dispersion of flavors in hard candies, soft drinks, and dill pickles. Emulsifiers are also used to disperse vitamin D in milk.

Emulsifiers are used for the volatile "sealed in" flavors of volatile oils (19). The volatile oil may be emulsified in gelatin or other suitable emulsifier and allowed to dry into granules. The gelatin creates a barrier between the flavor oil and the air. These granules can be used in gelatin desserts or other products.

Various emulsifiers are constantly being tried out. Some of them will be used, others will be dropped by the wayside, when cheaper, more efficient emulsifiers will do the job. Some of these products are discussed in various articles (11, 20, 31, 34, 39).

Amount of emulsifier. There must always be sufficient emulsifier to stabilize the emulsion. But the amount of emulsifier needed may vary for the same dispersed constituent under different circumstances. A good example is milk fat. In milk and cream the fat is stabilized by phospholipids and proteins. During homogenization of the ice-cream mix the surface area of the fat globules is increased enormously. As a result there is too little emulsifier to keep the fat emulsified and serum solids are added to aid emulsification.

Classification of emulsifiers. Of the many methods of classifying emulsifiers, one is to classify them according to the method of stabilization as follows: (*a*) an electric charge, (*b*) colloids, (*c*) powders, and (*d*) salts.

The electric charge is the means whereby the oil hydrosols are emulsified. In addition, the electric charge has a role in stabilizing emulsions with all types of emulsifiers but is not the sole factor in stabilization. The oil particles of oil hydrosols are negatively charged.

Colloids are the most important emulsifying agents in food preparation. Most of them can be highly hydrated, and many are found in natural foods as well as in prepared ones. Proteins are among the most efficient emulsifiers, some being more efficient than others. Fraser (17) found in investigating the emulsified fat particles of blood serum that globulin is preferentially absorbed over albumin at the interface of the two liquid phases in a mixture of the two proteins. He also finds that in finely dispersed oil-in-water emulsions stabilized by protein the dispersed phase is not soluble in fat solvents. Precipitation reactions of the particles are characteristic of the particular protein used for protection. Proteins of eggs, milk, flour, gelatin, and the starches are common emulsifiers used in food.

In addition to proteins other colloids are used for emulsifiers. Starch has been mentioned. Fat derivatives such as mono- and diglycerides are also used.

Stabilization by powders. Finely ground powders such as lampblack, mustard, and paprika are a third class of substances used for emulsifying agents. Paprika, mustard, and other powdered spices are used in French dressings but are not sufficiently good emulsifiers to keep the dressing stable without the use of one or a mixture of the emulsifiers permitted in the product.

Clayton (10) reports the results of using finaly divided solids as emulsifiers by Bechhold, Dede, and Reiner. "They found that the formation of emulsion depends upon: (*a*) The grain size of the powder. The smaller the grain the better the emulsion, until an optimum is reached, after which smaller grains have inferior emulsifying properties. (*b*) The quantity of powder. The more powder there is available the more globules there can be covered, providing the powder is sufficiently fine." They report that zinc dust, iron powder, clay, Kieselguhr, and yeast make very efficient emulsifiers.

Salts. As previously given, several salts may be used separately or combined as emulsifiers.

Efficiency of different substances as emulsifiers. No study has been made to compare the efficiency of all emulsifiers under different conditions and for different emulsions, and when emulsifiers have been compared it has often been with inedible emulsions. Thus Clark and Mann (9) formed emulsions of benzene and kerosene in water, the oils composing 75% of the total volume. The emulsions were made by shaking in a bottle, the oil being added in 3 parts and a total of 4800 shakes used in making the emulsion. With benzene and a 1% solution of each emulsifier the order was as follows: egg albumin, 10; starch, 6; gum arabic, 5; dextrin, 3; sucrose, 0. With kerosene the order was as follows: egg albumin, 10; starch, 9; gum arabic, 3; dextrin, 2; sucrose, 2.

Clark and Mann also determined the efficiency of the above emulsifying agents in the presence of electrolytes. In some cases the electrolytes increased the viscosity; in others they lowered it. They concluded that "no one general rule can be made as to the effect which produces the best emulsions for any one substance nor can any one generalization be made for the effect which produces the best emulsion for all substances under all conditions. Those which seem to be of primary importance are viscosity and film formation."

Food emulsifiers. Egg yolk is the outstandingly efficient food emulsifier. It is rated four times as efficient as egg white (6), with whole egg intermediate for mayonnaise. For a salad dressing of the O/W type (see Experiment 33F) neither gelatin nor starch paste is as efficient as egg white. The efficiency of the gelatin, however, is said to vary (10) with the *p*H of the gelatin, less being required at *p*H 2.8 than at 5.5, and in turn less at *p*H 5.5 than at 9.6. Then too the quantity used affects the efficiency.

Stability of Emulsions

Stability in emulsions means that the dispersed particles do not coalesce and form a separate layer. King (28) states that all emulsions are unstable systems. The dispersed droplets tend to join each other. The time for this to occur varies widely in different emulsions, some systems taking years to break. Some of the factors affecting the stability of emulsions are: (*a*) the emulsifier, (*b*) the concentration of the emulsifier, (*c*) the viscosity of the external phase, (*d*) the ratio of the dispersed to the external phase, and (*e*) the particle size.

The function of the emulsifier is twofold. It aids in forming the emulsion and in stabilizing it. The extent to which the emulsifier lowers the surface tension affects the stability. With a high interfacial tension the emulsion is difficult to form and very unstable. King considers the strength and compactness of the interfacial film the most important factor in the stability of emulsions. He thinks that other factors are important only as they modify the properties of the film. He adds that the concentration of the emulsifier in bringing about stability is too little stressed. The importance of the concentration of the emulsifier can be illustrated in many food emulsions; cream puffs and mayonnaise may be cited as examples. King states that, if the concentration of the emulsifier is sufficient so that a coherent film forms around the oil globules in an O/W emulsion, the stability of the emulsion is not seriously affected by the addition of electrolytes. Some emulsifiers are very sensitive to the addition of calcium and/or magnesium.

Many investigators stress the importance of the viscosity of the external phase in producing stable emulsions (5, 7, 28, 40). Since the dispersed particles are enclosed in the interfacial film their viscosity does not affect that of the emulsion. A viscous emulsifier permits less coalescing of the dispersed particles. The proteins and gum which produce viscous sols or gels with very small concentrations are good illustrations of viscous emulsifiers.

As the amount of oil added to the emulsifier is increased the emulsion becomes stiffer and more viscous. Sutheim (40) suggests that this viscosity increases the stability of the emulsion. Decreasing the size of the dispersed particles increases the stability of the emulsion. A good example of this is homogenized milk. The optimum range of particle size in emulsions (40) is probably between 0.5 and 1.5 μ.

The stability of emulsions is affected by temperature change. High temperatures coagulate some food emulsifiers. If the film is broken or dehydrated during this process, breaking of the emulsion occurs. Freezing causes separation in mayonnaise. In freezing the water is withdrawn to form ice which destroys the film.

The Making of Emulsions

In a few instances (23), when the surface tension is lowered enormously, the emulsion may form almost spontaneously. But the making of most emulsions requires considerable energy in the form of work. Most of this work is done to separate the dispersed phase into smaller particles.

This does not imply that the agitation reduces the dispersed particles to the size found in the completed emulsion. In making mayonnaise, after the emulsion has started, relatively large quantities of oil can be incorporated with only slight agitation with a fork or spoon. This agitation can be kept to such a minimum that common sense rules against the agitation reducing the oil particles to minute size. Agitation is very important in that it increases the surface area of the dispersed phase at which the emulsifier can be adsorbed.

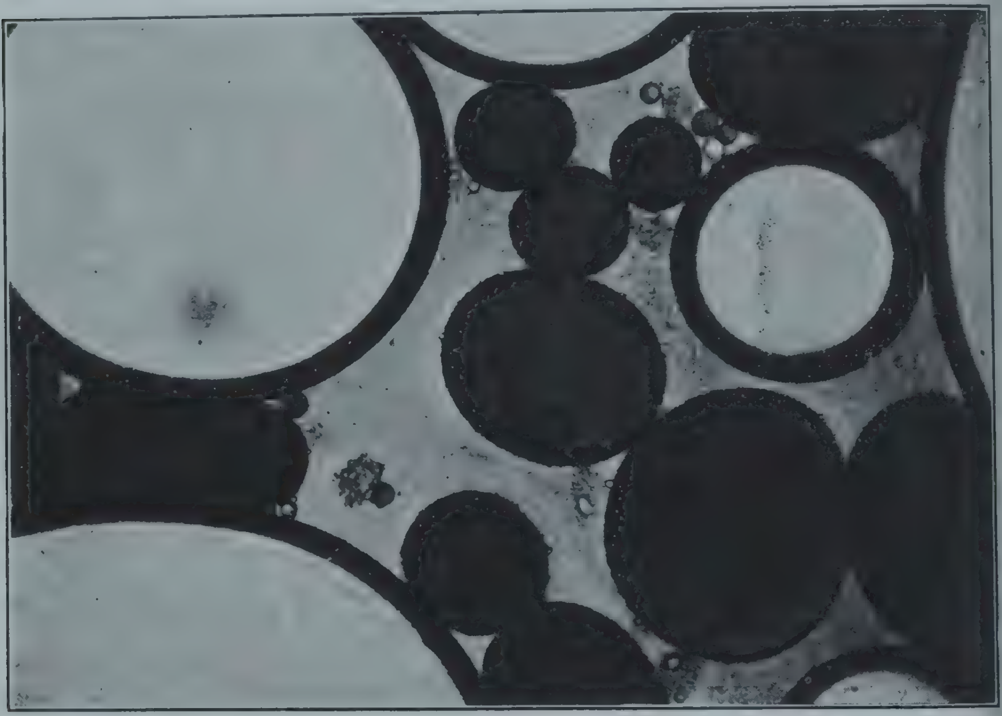

FIG. 41. A coarse emulsion of oil in egg white. Egg white will not foam if a fat like butter or lard is added to it, but with oil both an emulsion and a foam are formed when beaten with an egg beater and the oil is added slowly. The large light spheres are air bubbles, the dark bands around them are probably an optical illusion. The oil is stained red so that the spheres appear dark in the photomicrograph. Magnification approximately x 135.

In Fig. 41 both an emulsion and a foam are shown. Batter and dough emulsions contain foams, and air is incorporated in homemade mayonnaise

Machines of different types are used for making commercial emulsions. In some, agitation is accomplished by stirring or beating; in some centrifuga force is utilized; in some one liquid is pre-atomized; and in others pressure is applied through colloid mills and homogenizers. Some commercial firms homogenize mayonnaise after it is formed by some other method. In making emulsions in the home different methods are followed. For mayonnaise a rotary egg beater may be used, French dressing may be shaken, and gravy and sauces are made by stirring, usually with a spoon.

Optimum degree of agitation for each emulsion. Clayton (10) says it is well known that agitation can both break and make an emulsion. "It is quite reasonable to believe that for any given emulsifying apparatus there exists an optimum speed or degree of agitation or mixing, and an optimum time of mixing or running, whereby the most perfect emulsion can be obtained in a given system. Experiments prove this."

Harkins (23) states that the "method used in preparing an emulsion is one of the factors determining the distribution, but the most striking feature of the present work is that the shift of the number maximum is so slight with the different methods of stirring employed." By number maximum Harkins refers to the number of particles of the dispersed phase in a definite volume.

Intermittent mixing for emulsions. Clayton (10) states that what may be termed the mechanics of emulsification is far from being understood even now. In some experiments in making different emulsions, investigators have reported that intermittent shaking is more effective than continuous shaking or agitation. Clayton believes that shaking is an inferior method of making emulsions, but that continuous shaking should give equally as good results as the intermittent shaking, provided that the emulsified portions are continuously removed from the mass. Intermittent agitation is explained as being more effective than continuous agitation, because of the rest periods, which allow time for adsorption of the emulsifying agent.

In making mayonnaise, the beating is often intermittent, for in stopping to add oil to the mixture, short rest periods occur.

Foams and formation of emulsions. Harkins (23), in commenting on the method of preparation of emulsions, states that in a number of tests the emulsion failed to form after stirring rapidly with a motor-driven egg beater for 5 minutes, which was not in accord with the usual emulsification in a few seconds. He found that in all these cases no foam was produced, and that as soon as a foam formed, emulsification occurred in a few seconds. This may be a factor in the formation of some emulsions in food preparation.

The effect of temperature. In general, rise in temperature increases the ease of emulsification. With most liquids the surface tension is lowered with rise in temperature. In addition the oil is more mobile or less viscous with rise in temperature. However, the effect on ease of emulsification of rise in temperature depends upon the relation of temperature to the adsorption of the emulsifier.

MAYONNAISE

Definition (15*b*). "Mayonnaise, mayonnaise dressing, is the emulsified semisolid food prepared from edible vegetable oil, one or both acidifying ingredients specified in paragraph (*b*) of this section, and one or more of the egg-yolk-containing ingredients specified in paragraph (*c*)."

The acidifying ingredients are vinegar or vinegar diluted with water or lemon or lime juice. Citric acid is an optional ingredient. The egg-yolk-containing ingredients are: liquid egg yolks, frozen egg yolks, liquid whole eggs, frozen whole eggs, or any one or more of the foregoing with liquid egg white or frozen egg white. The seasoning may be salt, a sweetening agent (sugar, dextrose, invert sugar, honey, sirups of corn, non-diastatic maltose, or glucose). Spices may be used unless the spice produces a color that may simulate the color of egg yolk. The finished product must contain 65% of oil.

Investigations on Mayonnaise and Emulsions

Condensation or peptization of oil globules. There is some evidence (24) that after mechanical dispersion of the oil during emulsification, depending on the diameter of the globules, a condensation or peptization of the oil occurs until an equilibrium regarding the diameter is reached. This equilibrium required a fortnight or longer for attainment. Thus mayonnaise, properly prepared, is more stable some time after than on the day of manufacture.

Air film on the oil phase. Hall and Halstrom (21) have reported that the presence of an air film on the oil phase, as it is introduced into the emulsifier and forming emulsion in making mayonnaise, results in a less stable, inferior emulsion with lower specific gravity than in mayonnaise prepared with oil having no such air films. For the emulsions having air films on the oil, the oil was added from a buret at a definite rate, the point of the buret being 6 inches above the surface of the forming emulsion. For oil having no air film the buret point was lowered so that the oil was injected beneath the surface of the forming emulsion. They add, "Clayton predicted that when the dispersed phase is injected into the continuous medium below the surface, intermittent injection would confer no advantage." From their results Hall and Halstrom felt that Clayton's prediction was a sound one.

Egg. Kilgore (26, 27) states that egg yolks are obtainable in five main conditions: frozen salted, frozen sugared, fresh refrigerated, especially treated, and dried. Their volume use in the mayonnaise trade decreases in the order given.

Snell, Olsen, and Kremers (37) have shown that the excellent emulsifying properties of egg yolk may be attributed to the lecithoprotein that it contains. They assumed that lecithin was the emulsifying portion of egg yolk and reasoned that adding more lecithin to the egg yolk would increase its effectiveness in emulsification. But all the mayonnaise so produced had poor consistency. They next studied the effect of each of the known major constituents of egg yolk on emulsification of mayonnaise. This led to the finding that egg yolk owes its excellent emulsifying properties to lecithoprotein. They found that the lecithoprotein constituted about 32.5% of the salted yolks.

Lecithoprotein is dominantly polar and gives an O/W emulsion. Egg yolk also contains cholesterol which has a dominant non-polar group and gives W/O emulsions. Sutheim (40) gives the following approximate composition of egg yolk: fats, 22.5%; proteins, 16%; phospholipids, mainly lecithin and cephalin, 10%; sterols, mainly cholesterol, 1.5%; minerals, 2.5%; and water, 48%. Chapin (7) found that the ether-insoluble portion (the "protein" and "lipoprotein" portion) is the most important emulsifying substance of whole egg. He also found that homogenization and low-temperature concentration reduce the emulsifying ability of the whole egg. Miller and Winter (32) found that pasteurization of whole egg and egg yolk for 4 minutes at 60–63°C before freezing did not impair their value for making mayonnaise under the conditions of their tests.

Freezing the egg yolk. There is no unanimity of agreement among investigators upon the effect of freezing egg yolk and whole egg upon their emulsifying ability in mayonnaise. This is probably accounted for by differences in formula, the method used in emulsifying the ingredients, and difference in eggs and other materials. Miller and Winter found that frozen yolk produced a stiffer mayonnaise than the fresh yolk under the same conditions. They had to reduce the amount of the frozen yolk to obtain an acceptable stiffness of their mayonnaise. On the other hand, Kilgore (26) states that more frozen yolk than fresh yolk is required to produce a mayonnaise of given stiffness. Chapin (7) found freezing had only a slight tendency to increase the emulsifying ability of whole egg. Miller and Winter found frozen whole egg produced a less stiff mayonnaise than the fresh whole egg.

Amount of liquid added to the emulsifier. Kilgore (26) emphasizes that the starting mixture to which the oil is added should not contain too much "free" water. It should have enough "free" moisture to start emulsification yet have a heavy body, like a thick paste, smooth in texture. Frozen and treated yolks, because they have more bound and less "free" water than fresh yolks, are excellent for starting mayonnaise to secure a fine "grain."

Emulsifying properties of mustard. Kilgore (27) found that an emulsion, which did not break after storage for 1 year, could be made by using a 4% mustard solution and 80% of oil. An emulsion made with 2% mustard solution had some oil on top after storage for 1 year. The mustard solution was obtained by adding mustard to water and filtering off the residues of undissolved material. About 70% of the mustard was found to be soluble.

The method of mixing. The method (12, 21, 26, 27) of adding the oil is emphasized as a factor in securing a stable emulsion of good consistency. Hall and Halstrom (21) found that the "compromise method" was the best. For this method a portion of the oil was added by means of a buret above or beneath the surface of the forming emulsion until optimum dispersion was obtained. They state that optimum dispersion might properly be considered the critical dispersion point. At this point maximum thickness is attained and any further addition of oil results in an irrecoverable breaking of the emulsion. This occurred after the addition of 30–35 cc of oil to 20 grams of beaten egg yolk. At this point the vinegar and spices are added. This thins the emulsion but thickening occurs again with the addition of the remainder of the oil. The amount of oil added was such that the mayonnaise contained 89–93% of oil.

For the method which Hall and Halstrom called American, the vinegar and spices were added to the egg yolk. After blending of these ingredients the oil was added in the same manner as for the compromise method. Their results are given in Table 22.

TABLE 22

STABILITY OF MAYONNAISE (*Hall and Halstrom*)

Method	Manner in which oil was added	Stability of emulsion after storing at 8°C for 2 years
Compromise	Above surface	Fragile, partially separated
Compromise	Beneath surface	No separation
American	Above surface	Complete separation
American	Beneath surface	No visible separation, but fragile

Factors Affecting the Ease of Formation and Stability of Mayonnaise

In making mayonnaise, several factors affect the formation of the emulsion, its stability, and ease of making. The major ones may be listed as follows: (*a*) degree and kind of agitation, (*b*) the method of mixing, (*c*) the ingredients used, and (*d*) temperature. Some of these may be further subdivided.

Degree and kind of agitation. This factor has already been partially discussed. Under it can be included the kind of apparatus as well as the rate of agitation. Good stable mayonnaises may be formed by both continuous and intermittent agitation. It has been demonstrated (21) that very stable mayonnaise may be formed by continuous agitation if the oil is added beneath the surface of the forming emulsion. It is also known that agitation may both make and break an emulsion (10).

The kind of bowl used. Some failures in making mayonnaise are due to putting small quantities of the egg yolk in a large mixing bowl. As a result the egg yolk spreads out in such a thin layer that the egg beater picks up very little of the egg, and an emulsion is not formed with the first portions of the oil added. A thick rod at the bottom of the rotary egg beater may hold the beater above the contents of the bowl, if the quantity of material in the bowl is small and the egg beater is held upright. Thus the surface area of the two phases coming in contact with each other (egg-vinegar and oil) are not increased sufficiently for an emulsion to form.

The method of mixing. Under the method of mixing may be grouped the following: (*a*) the method of adding the oil, (*b*) the quantity of oil that is added at first, (*c*) the time of adding the vinegar, and (*d*) the time the seasonings are added.

The method of adding the oil. Hall and Halstrom have shown that a more stable emulsion is formed when the oil is added beneath the surface of the forming emulsion.

The quantity of oil that is added at first. Mark (30) states: "(*a*) If the proportion of oil to that of egg or of the emulsion already produced was kept below a certain maximum a stable emulsion always resulted, no matter what the temperature or manner of beating; (*b*) if the proportion of oil added exceeded a certain maximum, the egg or the emulsion already formed became dispersed in oil and no permanent emulsion was formed; (*c*) if the proportion between these limits were used a permanent emulsion might or might not be formed, dependent on such variables as manner of beating and temperature; (*d*) if egg was previously diluted by adding vinegar the proportion of oil which could be permanently emulsified was greatly increased during the addition of the first and second portions of oil, but that as viscosity of the mixture increased the maximum ratio of oil to emulsion rapidly approached the value found when egg alone was used at first."

No recent experiments have been reported showing the amount of oil that can be added for the first instalment in making mayonnaise. It has been reported [Smith by Brooks (6)] that if beaten 10 seconds with 10-second rest periods, the amount of oil that can be added to 10 cc of egg yolk for the first time (no seasoning or vinegar added) is 3–4 cc. It has also been reported that if the rest period is increased to 25 seconds as much as 6.5 cc of oil can be put in for the first addition.

When the seasonings and vinegar are put with the egg yolk before any oil is added (Experiment 33, C2) usually 40 grams of oil can be used for the first amount. Occasionally some students can add 50 grams of oil. However, much depends on the temperature, the length of beating, and the length of the rest periods before more oil is added. The time for emulsification with varying amounts of oil for the first portion appears to follow a logarithmic rule. If the addition of 2 cc of oil requires 5 seconds for emulsification, then 4 cc requires about 25, and 8 cc about 125 seconds.

Mayonnaise is formed more readily if the first quantity of oil is small. All the oil can be added in a continuous stream and be emulsified in less than 50 seconds for the proportions given in Experiment 33, provided that the seasonings and vinegar are mixed with the egg yolk before the oil, and that the first oil is poured in a fine stream with continuous beating.

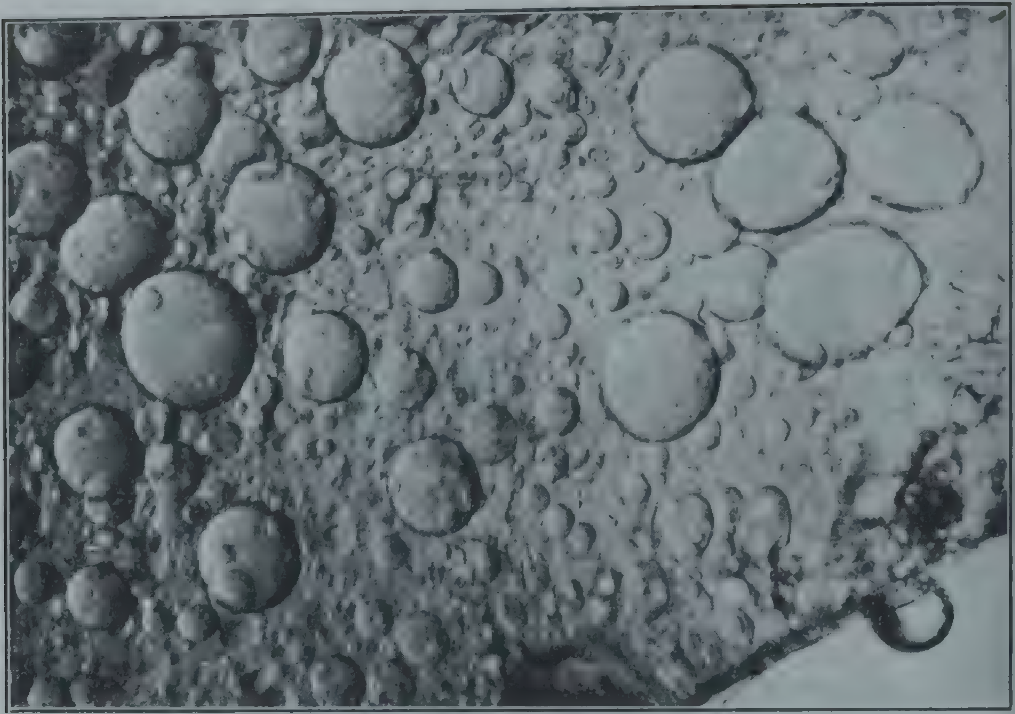

FIG. 42. Mayonnaise. Showing the coarse emulsion formed after the addition of 1 tablespoon of oil. The vinegar and seasonings were added to the egg yolk before the oil was added. Magnification approximately x 200.

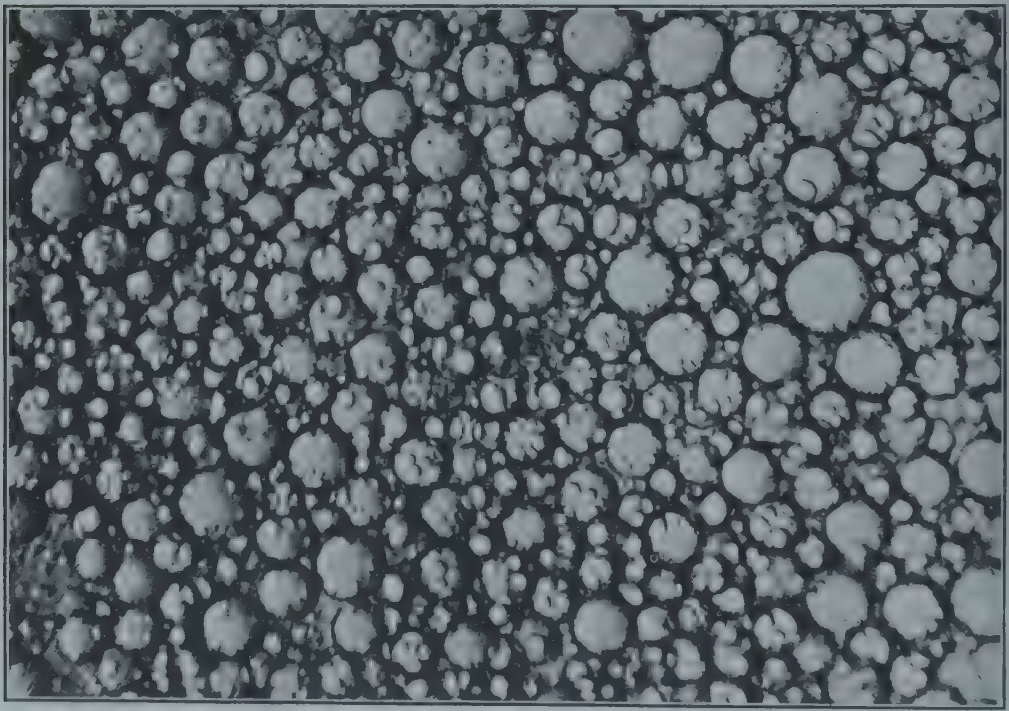

FIG. 43. Mayonnaise. Same as Fig. 42, but after adding ¼ cup of oil. Magnification approximately x 200.

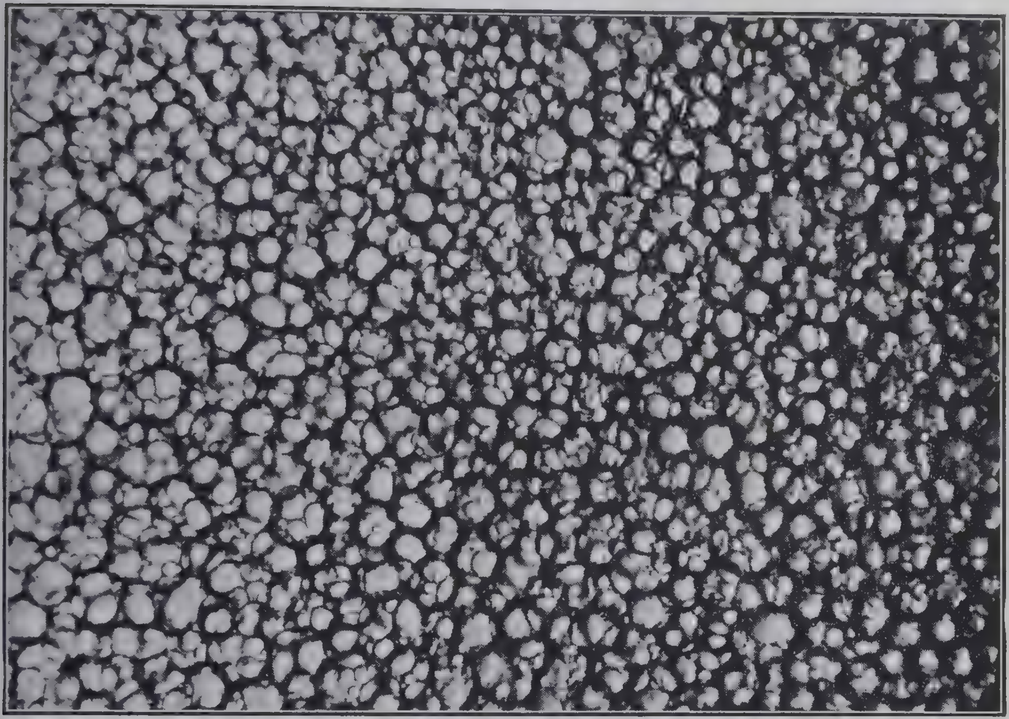

FIG. 44. Mayonnaise. Same as Fig. 43, but after adding ⅜ cup of oil. As the oil spheres become smaller with the addition of more oil the mayonnaise becomes stiffer. Magnification approximately x 200.

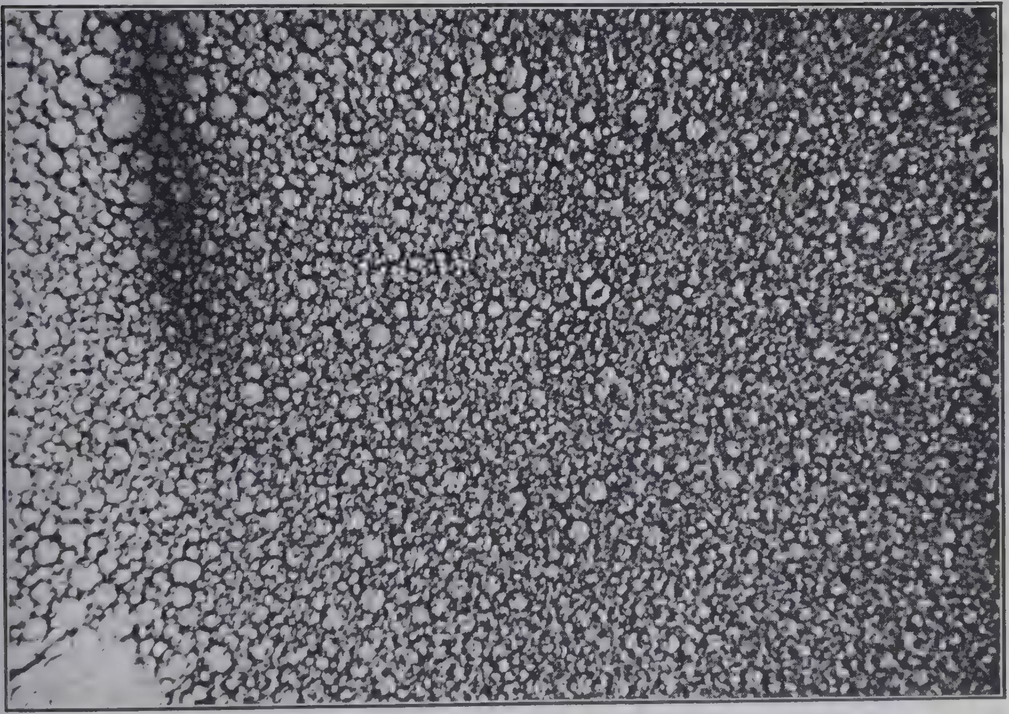

FIG. 45. Mayonnaise. Same as Fig. 44, but after the addition of ½ cup of oil. Magnification approximately x 200.

The time of adding the vinegar. Part or all of the vinegar may be added at various intervals during the making of mayonnaise (Experiment 33A, 1, 2, 3, 4) as follows: (*a*) alternately with the oil, (*b*) after considerable oil has been emulsified, (*c*) before the oil, or (*d*) by Kilgore's method (given below). When the vinegar is added before the oil, larger quantities of oil for the first and second portions can be used and the mayonnaise forms more rapidly. When all the vinegar is mixed with the egg yolk before any oil is added, the first oil particles emulsified are quite large, but with each subsequent increment of oil the dispersed particles become smaller and smaller, the mayonnaise stiffer. This is shown in Figs. 42–45, which are photomicrographs of mayonnaise. On the other hand, if some oil is added to the egg yolk without vinegar, the initially emulsified particles are small, yet become smaller with subsequent increases of oil, until the emulsion finally breaks. The addition of vinegar at any stage of emulsification causes the dispersed particles to coalesce. As the emulsified oil particles increase in size the mayonnaise becomes thinner.

Kilgore suggests the following method. The salt, mustard, and other dry ingredients are mixed with the fresh egg yolks, for they aid in holding excess moisture. With this is blended just enough vinegar to make a heavy paste. Then run in half the oil, a third of the vinegar, the rest of the oil, and the remainder of the vinegar.

Corran (12) suggests that the emulsification be carried out in three stages. (*a*) The dry ingredients, egg yolk, and part of the aqueous ingredients are mixed thoroughly. (*b*) All the oil is added, forming a creamy nucleus. (*c*) The creamy nucleus is diluted with the remainder of the aqueous ingredients.

The ingredients used. These include the oil, the salt and seasonings, the vinegar, the egg yolks, and even previously emulsified mayonnaise. Any of the edible oils may be used in mayonnaise.

The oil. No studies have been reported showing the effect of different oils in the stabilization of mayonnaise in which an analysis of the oil is given.

The salt and seasonings. Salt, mustard, paprika, and pepper are usually added to mayonnaise. Small amounts of other seasonings may be used. Pasteurized spice mixtures are also available to the mayonnaise manufacturer. Both salt and seasonings (38) increase the stability of mayonnaise. Salad dressing made with the proportion of egg and oil given in Experiment 33, but omitting the vinegar and seasonings, is very stiff and viscous, but is not stable and molds grow readily on its surface even in the refrigerator. If the vinegar is added, the dressing is thinner, but more stable, and keeps better. However, adding salt with the vinegar increases the stiffness decidedly, as determined by penetrometer and mobilometer tests. Adding the rest of the seasonings again increases the viscosity. The addition of an electrolyte to an emulsion may produce varying results, depending upon the electrolyte, the emulsifier, and the type of emulsion. Some electrolytes cause reversal of certain emulsions; others may tend to stabilize the emulsion. Seifriz in his work with emulsions stabilized with casein found that NaCl had no influence on the water-in-oil emulsions, but tended to stabilize oil-in-water emulsions. The effect of NaCl would probably vary with the emulsifier and the concentration of the salt. Krantz and Gordon (29) found that the concentration of the sodium chloride affected the stability of some emulsions. Calcium salts, since they tend to form water-in-oil emulsions, are detrimental to mayonnaise. Hence it is recommended that the salt used should contain less than 0.1 per cent of foreign calcium salts. Kilgore's results indicate it is preferable to add the mustard to at least part of the vinegar to make a paste, which is then mixed with the egg yolk.

The egg yolks. Some early work (6) indicates that egg yolks of high quality produce more stable mayonnaise than those from aged eggs.

The addition of a small amount of emulsified mayonnaise. Mayonnaise is very easily made if from ¼ to ⅓ cup of previously made mayonnaise is added to the egg yolk and vinegar. This gives a larger quantity of material to work with, but if an emulsion is already started the emulsification of additional oil is accomplished more readily. After an emulsion is once formed, subsequent additions of oil are very easily emulsified. This is analogous to seeding in crystal formation and the addition of an old gel to gelatin to hasten jelly formation. Egg yolk is itself an emulsion containing about 30% of fat.

Kilgore states, "This trick of starting an emulsion, or 'seeding' it, by means of one previously made is common in pharmaceuticals. It is the fundamental principle of a process for continuous emulsification."

Breaking Mayonnaise

Water may separate at the bottom of a mayonnaise after long standing. Robinson (35) states that this seldom occurs if the amount of water in the mayonnaise does not exceed 15%. With the percentage of water higher than 15 the separation occurs more frequently.

Oil may separate at the top of the mayonnaise. Anything that destroys the film-forming properties of the emulsifying agent and lets the dispersed phase run together destroys the emulsion. Overheating, when the oil and liquid expand at different rates, the addition of salts that precipitate the emulsifier, drying of the surface, freezing, and jarring may all cause separation in mayonnaise.

Agitation or shaking in shipping tends to break the emulsion. Evaporation from the surface of the mayonnaise may cause drying of the emulsifying agent and consequently coalescing of the oil on the surface. Mayonnaise keeps better in covered containers which prevent evaporation. Fischer and Hooker (13) state that, if the protein emulsifier is diluted beyond the point at which it will take up all the water, the emulsion tends to break.

Heating, resulting in too much evaporation of the liquid, causes separation of the fat in gravies, sauces, and cream puffs.

Reforming broken mayonnaise. The usual procedure to reform broken mayonnaise is to take a new egg yolk and add the curdled, broken mayonnaise to this gradually. It is added and beaten in the same manner as when the oil is originally added to the egg yolk. But it is not necessary to use egg yolk to reform the emulsion. The broken emulsion can be reformed by adding it gradually to a tablespoon of water or vinegar with beating. It will not reform if the water or vinegar is added to the mass of broken emulsion. See Experiment 33, D.

The Concentration of Oil in Mayonnaise

The amount of oil that can be permanently emulsified varies with the emulsifier, the oil used, and the manner in which it is added. Pickering (33) has emulsified 99% of paraffin oil in 1 cc of 1% potash solution by successive addition of small portions. The concentration of oil in food emulsions varies from a very low percentage up to about 85%.

Mayonnaise containing slightly more than 95% of oil has been made in the laboratory, but it usually breaks shortly after a little more than 90% of oil has been added. The stiffening of mayonnaise containing over 90% of oil makes it difficult to mix the last addition of oil. Mayonnaise with more than 90% of oil resembles jelly in consistency; when cut with a knife or spoon it retains its shape. It will keep varying lengths of time in a covered jar in the refrigerator. Some break in a short time, but most of them keep for several days or weeks. After standing a short time, if the dressing is cut or if some is lifted out of the jar, there is a tendency for oil drops to form gradually on the cut surface. It separates more readily than mayonnaise with a lower percentage of oil. Ordinary mayonnaise, containing the proportions given in Experiment 33, averages 65–75% of oil. Hall and Halstrom (21), by introducing the oil beneath the surface of the forming emulsion, obtained mayonnaise with a concentration of 89–93% of oil that remained stable for two years when stored at 8°C.

Some Food Emulsions

In cookery, the liquid of the emulsion may be water, milk, an acetic acid solution or fruit juice, a cooked starch paste, egg yolk, whole egg, or a mixture of milk and egg. The fat or oil may be any edible one. In food preparation, mayonnaise is usually mentioned first as a typical emulsion. Milk is an emulsion. Egg yolk has fat emulsified in it; butter and margarine are emulsions which must contain 80% fat, the rest is salt, protein, and water. All gravies, sauces, and cream soups are emulsions. Fillings for pies like butterscotch, chocolate, and lemon may be added to the list. All French, cooked dressings, and salad dressings are emulsions. In batter and dough products the fat is partially or wholly emulsified.

An interesting emulsion can be made from the drippings (containing fat and other materials) from a pan-broiled steak or chop. If more milk than fat is added to the drippings and brought to a boil, the fat is wholly or partly emulsified. If 20% cream is used instead of milk the emulsion forms with less boiling, and is more stable.

Salad dressings. The Food and Drug Administration (15*b*) gives standards for three food dressings. They are mayonnaise, salad dressing, and French dressing. Salad dressing differs from mayonnaise in that a cooked starch paste replaces part of the oil. The amount of egg yolk ingredient is specified. The emulsifiers that are permitted in French dressing are optional ingredients in salad dressings. Thus salad dressing may have one or more emulsifiers in addition to egg yolk and the cooked starch paste.

French dressing contains not less than 35% of vegetable oil by weight. It may contain egg-yolk ingredients, emulsifiers, and tomato paste, tomato puree, catsup, or sherry wine.

There are, of course, many dressings used for salad and foods for which no standards of identity have been promulgated. These include cooked dressings containing butter and fruit juices thickened with starch and/or egg. They also include such dressings as Thousand Island, Russian, etc., which may have mayonnaise or French dressings as a base. These were all called salad dressing long before the present definition of salad dressing was promulgated. Among homemakers they will be known as salad dressing, but the author wonders what they can be called legally. Mineral oils are no longer permitted in dressings for which definitions have been promulgated because of its adverse effect upon absorption of fat-soluble vitamins from the digestive tract.

Emulsions stabilized with flour. In gravies and sauces the amount of oil that can be permanently emulsified is much smaller than in mayonnaise. Gravies and sauces in which the oil separates may be made smooth again by adding water and stirring while heating. The addition of water lessens the percentage of oil in the product. Emulsions stabilized with flour or starch need a higher percentage of water than mayonnaise. This type of emulsion belongs in the class of hydrated colloids referred to by Fischer and Hooker (13), in which the water must not be reduced below a lower limit and must not exceed an upper limit.

Cream puffs. Cream puffs are good examples of a batter in which the fat is emulsified. See Chapter 13, Experiment 53. In the recipe as given in the experiment, the fat constitutes about 17% of the uncooked ingredients, if the fat content of the butter is used as 85, the eggs as 10.5, and the flour as 1.5%. The cooking of the water, flour, and fat will increase this percentage, as will the baking, on account of evaporation of water. The fat does not run or ooze out of the dough while the puffs are baking.

If the eggs in the recipe are reduced to 2 but no other change is made, Experiment 53 C, 2, the percentage of fat in uncooked materials is about

18.6. The fat in these puffs runs out of the dough and over the baking pan in large quantities while baking. With the smaller quantity of egg the emulsion does not hold, but if the amount of water added is increased to 1¼ cups when the eggs are reduced to 2, the amount of fat in the uncooked ingredients is about 17%. The fat in these puffs does not ooze out while they are baking. Although the quantity of egg is important, this also shows that it is essential to have a definite proportion of liquid to prevent breaking of the emulsion.

Hollandaise sauce is an emulsion (see Chapter 11, Experiment 43). The percentage of oil is rather high (about 40–50) so that heating must be done carefully and at a low temperature or the emulsion will break. With 4 egg yolks the sauce is usually ready for serving when heated to 67–70°C, and with 2 egg yolks at a slightly higher temperature.

Batter and dough products. The oil or melted fat used in griddle cakes, waffles, and muffins is dispersed as an oil-in-water emulsion.

Cake. The fat in a cake batter may be wholly or partly emulsified. A microscopic study of cake batters shows that there is a tendency for oil to be emulsified as oil-in-water emulsions, no matter what the method of mixing. When butter or hard fats are used the fat may be partly emulsified as water-in-oil emulsion and partly distributed as films of fat between the other ingredients. Sometimes both oil-in-water and water-in-oil emulsions are formed. This probably occurs more frequently when the temperature of the ingredients is close to the melting point of the fat.

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EMULSIONS

Experiment 33.

To determine some of the factors that affect the formation and stability of emulsions.

Mayonnaise:

Egg yolk	1	18 grams	Mustard	¼ teaspoon
Vinegar	1 tablespoon	15 grams	Paprika	¼ teaspoon
Oil	½ cup	108 grams	Sugar	½ teaspoon
Salt	½ teaspoon			

In studying emulsions, a microscope is a great aid. For very fine emulsions a small portion is placed on a slide and covered with a cover glass. With coarse and unstable emulsions it is better not to use a cover glass for the weight often breaks the emulsion. If the oil or fat is colored a dark red with Scarlet R, the type of emulsion formed can be determined with the microscope. An oil-in-water emulsion has a red oil dispersed in small spheres; a water-in-oil emulsion has a red field and light-colored spheres. To color the oil or fat, add the powdered Scarlet R and then stir. It should stand overnight to dissolve the dye thoroughly.

Store the emulsions in jelly glasses. Label, then cover the glasses to prevent evaporation. Put away in the refrigerator to determine the permanency of the emulsion.

A. To determine the effect of varying the method of combining the ingredients in making mayonnaise.

1. Put the egg yolk into a small bowl, add the seasonings and the vinegar, and beat with a rotary egg beater. It may be necessary to tilt the bowl or egg beater at first, in order that the egg beater blades may come in contact with the small amount of material. Add the oil in small quantities at first, about ½ teaspoon, then in larger quantities as the emulsion is formed.

2. Mix the egg yolk and seasoning. Follow directions under A1, for beating. Add about ½ teaspoon of oil. Beat, then add ½ teaspoon of vinegar. Beat. Continue adding oil and vinegar alternately. After all the vinegar is added, add the oil in larger quantities.

3. Beat the egg yolk. Follow directions under A1, for beating. Add the oil a few drops at a time. After the emulsion is forming, add the oil in larger quantities. Add the vinegar slowly after the oil is added. Add the seasoning last.

4. Add the seasonings and ⅓ of the vinegar to the egg yolk. Then add gradually approximately ½ of the oil. Next add ⅓ of the vinegar, then gradually the last of the oil followed by the last of the vinegar.

B. To determine the effect of the temperature of the ingredients in making mayonnaise.

1. Add the vinegar and seasoning to the egg yolk. Beat. Chill in the refrigerator, then set mixing bowl in ice, and add chilled oil slowly. Follow directions under A1, for adding the oil.

2. Heat the oil and vinegar to 100°C. Combine as in A1.

C. To see how much oil can be added for the first addition to 1 egg yolk and 15 cc of vinegar and obtain an emulsion.

1. Repeat A1, but add 30 grams of oil at first, then beat and emulsify thoroughly before more oil is added. Add the same amount of oil for the second portion; then increase the amount for the following additions of oil.

2. If 30 grams of oil can be added under C1, repeat with 40 grams of oil. If an emulsion is obtained start another emulsion with 45 grams of oil. Repeat, increasing the quantity by 5 grams for the first addition of oil until no emulsion is obtained.

D. To determine the amount of oil that can be added to mayonnaise without breaking the emulsion.

1. Follow directions under A1, but add all the oil possible to the mayonnaise. Keep a record of the amount of oil added. Compare the consistency of the mayonnaise with that obtained in other experiments. Determine its keeping qualities.

2. Repeat D1, but add oil until the emulsion breaks. If oil has been added until the emulsion breaks under D1, use it for this experiment and repeat D2, but do not add quite so much oil. Put a small portion of the broken emulsion, about a tablespoon, in a jelly glass. Label and cover. Divide the remaining broken mass into four parts. Save one portion. Compute the percentage of oil added for D1 and D2.

a. Add part one to an egg yolk gradually, beating with the egg beater during the process. What happens?

b. Repeat D2, *a,* but add the second portion of curdled emulsion gradually to a tablespoon of water or vinegar.

c. Add a tablespoon of water or vinegar to the third portion of broken emulsion. Beat. What happens?

E. To determine the kinds of fat that may be used in food dressings.

1. Repeat A1, reducing the fat to 90 grams and substituting butter for the oil. Melt the butter over hot water, and keep warm while adding to the egg yolk and seasonings.

2. Repeat E1, but use lard or a shortening.

F. To determine the effect of substituting other emulsifying agents for the egg yolk in making salad dressing. Combine by method A1.

1. Substitute 1½ tablespoons of cornstarch paste for the egg yolk in the mayonnaise recipe. (Make the paste by cooking 2 tablespoons of cornstarch with 1 cup of water.) When the paste is cool but not firm, add the seasonings and vinegar to 1½ tablespoons of the paste, and beat with rotary egg beater. Add the oil slowly at first, then more rapidly after the emulsion begins to form.

2. Substitute 2 tablespoons of gelatin solution for the egg yolk in the mayonnaise recipe. (Make gelatin solution by using 3 teaspoons of gelatin to 1 cup of water.) When the gelatin is thick but not firm put 2 tablespoons in a mixing bowl. Add the seasonings, and the vinegar. Beat. Add the oil slowly at first, then more rapidly.

3. Substitute 18 grams of egg white for the egg yolk.

4. Substitute 18 grams of whole egg for the egg yolk.

Is there much difference in the method of combining ingredients for mayonnaise when egg yolk is used as the emulsifying agent? What effect does the temperature of the ingredients have on the formation of an emulsion? What is the largest quantity of oil used for the first addition of oil when a permanent emulsion was obtained? How much oil did you succeed in adding to the mayonnaise? By examining the emulsions obtained under the microscope, compare cornstarch paste, gelatin, egg white, and egg yolk as emulsifying agents for emulsions.

G. To show that the emulsifier peptizes the oil phase.

After the emulsions have been stored and compared, take a bowl large enough to hold all the combined mayonnaise. Put the remaining mayonnaise from two experiments in the bowl, being sure they are stable. To this quantity add one-half as much of a broken emulsion. Stir slowly with a spoon or fork, stopping frequently for rest periods. The mass will appear curdled and broken, but continue the stirring, slowly and with rest periods. Note that as the emulsion forms the pull on the spoon during stirring becomes greater and is noticeable long before the visual appearance denotes that the emulsion is forming. The proportion of broken mayonnaise added can be increased provided that it never exceeds the volume of the emulsion already formed. However, longer stirring and more rest periods are required as the proportion of broken emulsion added at one time is increased. After the emulsion reforms, add the remaining broken emulsions in the same manner and finally the remaining good ones (with the exception of those made with colored oils). This experiment is to show that the emulsifier does the major portion of the work, and that stirring is only necessary to bring larger surfaces of the oil and emulsifier in contact with each other.

Experiment 34.

To determine the type of emulsion formed with different emulsifying agents and oils or fats.

Use oil or fat stained with Scarlet R. Continue beating the mixture for a few seconds after all the fat or oil is added, even if at first it appears that an emulsion will not form. Examine portions of different steps under the microscope.

1. Use a deep, narrow bowl and a rotary egg beater. Add 25 grams of melted butter gradually to 25 grams of egg white.
2. Add 25 grams of melted butter gradually to 25 grams of casein solution, Make the casein solution by adding some powdered casein to water and stir to dissolve as much as possible. After it settles use the clear liquid. The experiment may be repeated using milk.
3. Repeat 52, 1, but use oil instead of butter.
4. Repeat 52, 1, but use lard or a shortening instead of butter.
5. Repeat 52, 2, but use oil instead of butter.

Suggestions for Additional Experiments

Determine the proportion of oil and liquid that are most stable in French dressing. Add gelatin, any of the commercial emulsifiers, tomato paste, and/or catsup to some tests.

Determine the proportion of egg yolk that aids in stabilizing the emulsion.

CHAPTER
10

Milk and Milk Products

In food preparation, milk is used in many ways and combined with many kinds of foods. All the different types of cheese are made from it. Meat, vegetables, and cereals may be cooked in it. It is used as a basis for many sauces, which may be combined with eggs, with meats, or with vegetables. It is used in puddings and in frozen desserts, for soups and for drinks like cocoa and coffee; it is combined with cereals; it is used in combination with many foods, as in custards, in cakes, and in all types of bread. One of its important uses is as a food beverage.

Milk from different animals is used for food, but in this country unless the source of the milk is mentioned it is understood to be cow's milk.

Composition of Milk

Cow's milk from herds varies in content of the different constituents (25). The widest variation is in fat content, with protein second.

Constituent	Range in Variation %	Average Content %
Water	84.0–89.5	87.25
Fat	2.6–6.0	3.8
Protein	2.8–4.0	3.5
Lactose	4.5–5.2	4.8
Ash	0.6–0.8	0.65

The following factors affect the content of the constituents of milk to a greater or lesser extent (19, 25, 62). (*a*) There is a wide variation in milk from different species. The composition of milk from each species is best suited for the growth of its young. (*b*) Jersey and Guernsey breeds have the highest average fat content, 5.0%, whereas Holstein has the lowest, 3.5%; that of Ayrshire and Shorthorn is between. There is a tendency for the protein content to parallel the fat content. (*c*) The stage of lactation: colostrum is very high in globulin content compared to normal milk. (*d*) Age and individual variations: the average fat content increases slightly with advancing age of the cow, and there is great variation in the composition of milk from individual cows. (*e*) There is variation from milking to milking; (*f*) with length of intervals between milkings; and (*g*) the average fat content varies during the milking period, the first-drawn milk being lower, the last-drawn higher in fat content.

In general, feed has only a slight effect on the concentration of the various milk constituents, although some constituents like iodine can be increased through the feed. Feed affects the flavor of the milk. Seasonal variation (25) is said to affect the fat content, the amount of fat decreasing as the cows go on pasture.

Kinds of Milk

Fluid milk. Whole or market milk (homogenized or unhomogenized), skim milk, and the fermented milks belong in this group. The bulk of the fluid milk is pasteurized. Pasteurization lessens the possibility of transmission of pathogenic bacteria and improves the keeping quality of the milk.

Homogenized milk is obtained by subjecting the milk to pressure. The milk is forced through small apertures so that the fat globules are reduced in size and increased in numbers. When the fat globules are reduced enough in size the milk does not cream; *i.e.,* the fat particles no longer rise to the surface of the milk. Small fat globules are less influenced by gravity than large ones, but the fat globules are also stabilized by phospholipids and proteins. As the surface area of the fat phase is increased by homogenization more phospholipids and proteins are adsorbed at the fat interface. It has been stated (81) that the amount of protein adsorbed may be increased from about 3% in unhomogenized to about 25% in homogenized milk.

Tracy (81) states that some advantages of homogenization are: homogenized milk (*a*) does not need mixing of fat and milk, (*b*) keeps better, (*c*) is more palatable, and (*d*) is easily modified for infant feeding. Other effects of homogenization (25) are: (*e*) the viscosity of the milk is increased (this is attributed to a larger proportion of the milk proteins being adsorbed owing to the greater surface area of the fat globules), (*f*) clotting properties are altered (a softer curd is given with rennet), (*g*) surface tension increases, and (*h*) rancidity of the fat develops faster in homogenized products. The cause for the last is given as greater hydrolytic breakdown of the fat by lipase enzymes on the additional surface area of the fat globules. This sounds contradictory, but one investigator is speaking of pasteurized homogenized milk, the other of the non-pasteurized milk. Homogenized market milk is pasteurized to inactivate the lipase enzymes that would cause deterioration in the flavor of the fat, as well as to destroy pathogenic bacteria.

Homogenized milk (32, 81) tends to curdle more readily than unhomogenized milk when used in soups, gravies, scalloped potatoes, cooked cereals, and custards. Tracy (81) states that milk proteins are destabilized by high temperature, low acidity, concentration of the milk salts, and homogenization. The *p*H of one lot of potatoes (81) was 5.65; these potatoes reduced the pH of the scalloped product to 6.07, whereas the normal pH of the milk was 6.5 to 6.6. Tracy reports that the higher the cooking temperature, the more the pH of the food combined with milk was lowered and, the higher the homogenization pressure, the more likely is the milk to curdle. Carr and Trout (12), on the other hand, found that homogenized milk custards had a slower rate of heat penetration and gave stiffer custards than the unhomogenized milk ones. Towson and Trout (80) found that sauces made with homogenized milk showed more fat separation than those made from unhomogenized milk. As the amount of fat used was increased the fat separation and size of the fat globules increased. Adding salt at the start of the cooking increased the size of the fat globules. Increased homogenization pressures also increased the apparent fat separation and the size of the fat globules. Beating the sauces made from homogenized milk with a rotary beater produced a smoother sauce. Sauces made with homogenized milk were stiffer than those made from unhomogenized milk.

Fermented milks are soured by the action of bacteria. These include buttermilk and culture milks. The culture milks include a wide variety of milks, many of which originated (62) around the eastern part of the Mediterranean Sea. Of these fermented milks, buttermilk (both conventional and culture) and Yogurt are the most popular because of their pleasant flavor (40). Fermented milk may be used for a beverage, for cooking, and for cottage cheese.

Condensed and evaporated milks. These milks are prepared by removal of part of the water from fluid milk. In general, manufacturers conform closely to the Federal standards for these milks.

Condensed milk. The average ratio for condensed milk is about 2.5 volumes of fluid to 1 volume of condensed milk. Sugar is added to preserve the milk without resorting to sterilization after condensing. The average amount of sugar in the finished product is about 40–45%. Sucrose or sucrose plus some dextrose is used. Dextrose cannot be used alone for (*a*) it is not as soluble as sucrose (for solubility see the chapter on sugar) and (*b*) it combines more readily than sucrose with the free amino groups of proteins to produce the browning reaction (see p. 25).

The milk is preheated before condensing. Hunziker (36) gives three major purposes of this preheating: (*a*) to satisfactorily use the vacuum pan (the milk entering the pan should be at or above the temperature at which the pan is operated), (*b*) to destroy pathogenic bacteria and inactivate enzymes, and (*c*) to improve the keeping of the milk, specifically to control age thickening. In condensed milk the lactose sugar forms a saturated solution. To prevent sandiness in the finished product, it is important that the milk be cooled rapidly. In rapid cooling many crystal nuclei are formed so that the lactose crystals are small and more uniform in size than if allowed to grow slowly.

Sweetened condensed skim milk and whey are manufactured, but not in large quantities. Sweetened condensed whey has marked whipping qualities. Ramsdall and Webb (60) have produced a candy in which the whipping properties of the whey can be utilized.

Evaporated milk. About 2.2–2.6 parts of the fluid milk are used for 1 part of evaporated milk. One of the most important steps in the processing of evaporated milk is forewarming. Forewarming increases the heat stability of the evaporated milk during subsequent heat sterilization.

The evaporated milk may be enriched with vitamin D. The evaporated milk is homogenized, then run into cans and sterilized. The milk is then cooled and shaken to break the soft curd formed during sterilization.

Dry Milks and Dry Milk Products

Dry milks and their products include malted milk, whole milk, skim milk or non-fat dry milk solids (NFMS), buttermilk, whey, cream, ice-cream mix, and sweetened condensed milk. The literature on dry milk is extensive. Coulter, Jenness, and Geddes (16) give a good review of the literature on dry milks with emphasis on the use of dry whole milk.

The use of dry milks for human food increased enormously during World War II, and their use has continued since the war. The amount of dry skim milk used for animal feeds (16) was 160,170,000 pounds in 1938 and 14,020,000 in 1948. But the total dry skim milk for human consumption during this same period increased from 289,121,000 to 658,515,000 pounds; the dry whole milk from 21,496,000 to 172,280,000 pounds. Most milks are dried by the roller and spray processes. Spray-dried milk particles are more uniform in size than the roller-processed dry milks but they also have more air entrapped in the particles. Lactose according to Troy and Sharp (83) is found in dry milks as a concentrated solution or glass. Fat is present in the form of globules, the degree of dispersion depending on various factors. Excessive heat treatment (16) denatures the milk serum proteins and may reduce the dispersibility of the powder.

The composition of some dry milks is tabulated. The figures are by courtesy of the American Dry Milk Institute.

	NON-FAT DRY MILK SOLIDS %	DRY WHOLE MILK %	DRY BUTTERMILK SOLIDS %
Protein (N × 6.38)	36.9	26.5	35.0
Minerals (ash)	8.2	6.0	8.0
Lactose	51.0	38.5	48.0
Fat	0.9	26.75	5.0
Moisture	3.0	2.25	3.0

The production of dry milk. The following factors are emphasized in obtaining high-grade dry whole milk. Some apply also to the non-fat or skim milks. The fluid milk should be sweet and of good quality; be clarified to remove sediment (33, 47); be homogenized to produce uniform-sized fat globules; be preheated (7, 27, 45, 47); be condensed before drying (46, 56); be dried to a low moisture content (29, 42, 72); and be gas or vacuum packed (42, 56). The shelf life of dry milks is longer if they are stored at low temperatures. The equipment should be free of copper and iron and kept in a sanitary condition. The powder should be removed promptly from the drying equipment and cooled.

Quality of dry milks. High-quality dry milks when reconstituted should closely resemble the milks from which they were made in flavor and physical characteristics. Mamus and Ashworth (46) state that, in judging the quality of dry milks, the first consideration should be palatability, and the second solubility. Since only lactose and some salts are in true solution, the term "dispersibility" is more apt than "solubility" in referring to constituents of dry milk. The principal cause of indispersibility is a change in the proteins, casein in particular.

Off flavors of dry milks. The terms used to describe off flavors of milk include: rancid, fishy, tallowy or oxidized, toffee, stale, musty, burnt feathers, heated, cooked, and caramelized.

Rancid. In the dairy industry the word rancid is used to describe the flavor of the hydrolysis products caused by the action of lipase on milk fat. Milk contains a larger proportion of the short-chain fatty acids than other fats commonly used in food preparation. Consequently the hydrolysis products impart their flavor to the milk, and in particular the irritating, pungent flavor of butyric acid. Development of a rancid flavor may be prevented by inactivating the lipase enzyme of the milk by heating before drying.

A fishy flavor is not a common defect of dry milk. Its origin is not always clear. In deterioration of butter a fishy flavor is attributed to formation of methylamine from lecithin. Its development is prevented by a low moisture content.

A tallowy or oxidized flavor is caused by autoxidation of the milk fat. The tallowy flavor can be prevented or its development retarded by preheating the milk before drying. The preheating temperatures, however, that have the most effect in preventing the tallowy flavor are often higher than necessary for inactivation of the enzymes. Hence the high temperature must produce some change that protects the fat of the milk from oxidation. Mattick et al. (47) found that dry-milk powder preheated to 88°C (190°F) kept in better condition for 2 to 3 times longer than similar dry-milk powder heated to 74°C (165°F). Sulfhydryl compounds were readily detected at the higher but not at the lower temperatures. These authors suggest that the better protection of the higher than the lower heat treatment is due to production of the antioxidant sulfhydryl compounds. Other investigators have also reported that dried milk has a longer shelf life if the preheating temperature is high (27, 45). The time of heating must be shortened at the higher temperature to prevent a strong cooked flavor and not to overheat the proteins. Krukovsky and Guthrie (38) think that oxidation of the ascorbic acid of the milk is an essential link in a chain of reactions resulting in the development of the tallowy flavor. Several factors affect the rate of development of the tallowy flavor. Davies (19) found that copper, light, and a rise in temperature have a catalytic effect. Davies found that the reaction velocity is doubled for approximately every 10°C rise in temperature. A stale flavor is also associated with the fat.

A *toffee flavor* (42) develops in gas-packed dry milks.

Heated and cooked flavors. The heated or pasteurized flavor is produced by pasteurization, whereas the cooked flavor is produced by sulfides formed at the higher temperatures. Gould and Sommer (28) found that the sulfides are produced when the fluid milk is heated quickly to 76–78°C. The temperature at which the cooked flavor occurred was lowered as the heating periods were lengthened, with an abnormally high *p*H, addition of sodium sulfite, and with a marked increase in fat content. On the other hand, the temperature of liberation of sulfides was elevated by adding lactic acid, by homogenization, and by decreasing the fat content. A close relationship between the cooked flavor and the liberation of sulfides was observed.

In later work (79) it was found that the amount of sulfides liberated is decreased by low or high *p*H, by sugars, cystine, NaCl, copper, and iron. Increasing the time or temperature of heating increased the liberation of sulfides. Homogenization, sunlight, and addition of certain salts had no effect. The heat-labile sulfides originate from two sources, the milk serum and the material associated with and closely attached to the fat globules.

Caramelized flavor is associated with the amino-sugar reaction and is found more often in condensed and evaporated than in dry milks, probably because of the low moisture content of the dry milks. Tarassuk and Jack (76) studied the amino-sugar or browning reaction in whole milk and ice-cream mix powders. They found that the discoloration is influenced by moisture content of the product and its storage temperature. If the moisture content was below 4% and the storage temperature 40°C or below, browning did not occur. See Chapter 1 for a discussion of the browning reaction.

Dispersibility of dry milks. For beverage purposes it is desirable that milk powder be dispersible in water with no sediment or flocks. The milk samples, the method of drying, the extent of condensation before drying, the drying temperature, the moisture content of the dry milk, the time and temperature of storage, all affect the dispersibility of the powder. The development of acidity or action of proteolytic enzymes lessens the protein dispersibility. Spray-dried milk powders are more soluble than the roller-dried ones (47). In spray drying the moisture is removed very rapidly. In addition the particles of dry milk are small. This aids in preventing overheating. Long, high heat treatment tends to lessen the stability of the milk proteins. This applies to both the preheat treatment and the drying temperature. Precondensing to 40% total solids (46) results in a powder of greater solubility than precondensing to 20% total solids.

Higher moisture content causes greater loss of solubility during storage (29, 42, 72). At high temperatures the reaction proceeds faster.

Malted milk is made by adding the liquid from a mash of ground barley malt and wheat flour to whole milk and then drying.

Dry ice-cream mix was prepared during World War II for overseas use by the Armed Forces. Its use has continued since the war. The production was 17,429,000 pounds during 1946 (36). A mix of the following proportions (36) meets the specifications of the Quartermaster Corps: 14 parts of 40% cream; 35.7 of 3.5% milk; 13.8 of plain condensed milk (30% SNF); 10.3 of sucrose; 2.5 of corn sirup; and 0.3 parts of stabilizer. Precautions in manufacturing are to preheat the liquid mix to 88°C for 5 minutes, and add only 25% of the sugar before drying and gas-packing.

Use of dry milks in foods. Dry milks may be used in foods in which fluid milk is used. The amount of milk that can be added will depend on several factors: the particular sample of dry milk; the product in which the milk is used; and whether the milk is reconstituted for use or whether dry milk is used in addition to fluid milk to increase the nutritive value. The optimum amount of dry milk will depend on the effect the added milk has upon the palatability and physical qualities of the product.

It has been found that skim milk solids increase the viscosity or gel strength of pastes in proportion to the amount of dry milk used (53). This increase in viscosity can be adjusted by a decrease in the amount of flour used.

O'Mally (54) states that the use of dry milks in prepared baked mixes improves the quality of the baked goods.

The preheating of fluid milk before drying improves the baking quality when the product is used in bread making (3, 15, 41).

Storage of dry milk in the home. Paul and Plummer (55) advise that dry milks be stored under refrigeration in the home, unless used within a short time after opening. Dry milks owing to their lactose content are hygroscopic and when exposed to air with average or high humidity absorb moisture. This allows the lactose to crystallize, and the powder becomes sticky.

Frozen Milk and Cream

Fluid milk or milk concentrated to a half or a third of its initial volume may be marketed in the frozen state. To date the principal use of the frozen concentrated milk is on shipboard. Cream has been frozen to hold it from a period of high to low production. A high preheating temperature (7, 14) is a protection against the development of a tallowy flavor. Fortification with 50 mg of ascorbic acid per liter (7) has been advocated to prevent an off flavor during storage. Heating develops a cooked flavor (7) which gradually disappears during storage.

Freezing and long storage may bring about changes in the milk (48, 88). The milk may thicken, the protein may flocculate, and the fat may partially separate. A lower storage temperature (5) keeps the milk normal for a longer time than a higher one. During freezing the solids content of the milk tends to concentrate in the portion of the milk that is frozen last. Agitation during freezing prevents this. The addition (5) of sodium citrate (2 g/liter) and ascorbic acid (0.1 g/liter) to homogenized milk frozen and stored at —11.50 and —17.8°C doubles the time that the milk remains normal in appearance and flavor after thawing.

Fat may also affect the distribution of the milk constituents during freezing (6). If the milk is not homogenized so that creaming is inhibited, the milk fat may partially come to the top of the milk. Increasing the fat concentration retards the diffusion of milk constituents into the unfrozen portion during freezing, possibly because of the increased viscosity or better sealing of the spaces between the ice crystals.

Tracy, Hetrick, and Krienke (82) found that milk concentrated to approximately 1 part for 3.5 parts of the fluid milk can be stored in the frozen state for 1 year with less flavor change than the same milk stored at the same temperature in the dried form (gassed or ungassed).

Constituents of Milk

The constituents of milk that are most important in food preparation are enzymes, vitamins, salts, sugar, fat, and proteins.

Enzymes. Milk (19, 25, 50, 62) contains three types of hydrolytic enzymes: (*a*) proteinase (galactase, which is inaptly named); (*b*) the carbohydrases, amylase and lactase; and (*c*) lipase. There is not complete agreement on the other esterases in addition to lipase. The following are listed in one or more of the above references: phosphatase, oleinase, monobutryinase, and solalase. In addition to the hydrolytic enzymes, milk contains the oxidizing enzymes catalase and peroxidase, and the reducing enzymes reductase (aldehydrase) and Schardinger's enzyme. Phosphatase (11) is heat sensitive and is used to detect irregularities in the pasteurization of milk. Warner and Polis (85) found that nearly all the proteolytic activity in milk is carried with the precipitate when the casein of milk is acidified.

Lipase (75) is activated by cooling the milk, the rate increasing with decrease in temperature. Holding the milk at 32–37°C for 1–3 hours profoundly retards lipolysis, even if milk is subsequently cooled. Mild churning-like agitation is also reported to activate the enzyme without cooling; the rapid growth of bacteria and development of acid hinder lipolysis.

Vitamins. All the vitamins recognized at the present time are contained in milk. Some are present in comparatively large and others in smaller quantities.

Pigments. Milk appears white because of the reflection of the light rays by the colloidally dispersed calcium caseinate and calcium phosphate and by the fat globules.

Milk contains two pigments, the fat-soluble carotene and a water-soluble lactoflavin (riboflavin). The carotene in the fat gives the milk a somewhat yellow tinge, which is more pronounced as the fat particles become more concentrated and form cream. The amount of carotene in milk varies with the carotene content in the food of the cow and with inheritance.

Salts. Although the salt content of milk is small, it is very important in the behavior of the proteins in food preparation. A good example is custard, which fails to thicken when heated unless sufficient salts are present. The elements (19, 62) present in greatest quantity in milk are: phosphorus, calcium, potassium, sodium, magnesium, chloride, and sulfur. The elements present in smaller quantity are: copper, average 0.52 ppm (71); manganese, 0.02–0.06 ppm; iodides, in small amounts; iron, 2–4 ppm; cobalt; and zinc, 3.6–5.6 ppm (9). Citrates are found in fresh milk. Lactates and other acid radicals may be formed by bacteria. When milk is dried and incinerated certain acid radicals such as citrate, lactate, and carbonate are volatilized. Other elements such as silicon are reported present in varying amounts.

The complex salt equilibrium in milk is not fully determined. It is known that some salts are found in solution, some in colloidal dispersion, some in combination with the proteins, some in two of these states, and at least two, calcium and the phosphates, are found in all three states. The citrates and the possible chlorides of K, Na, and Ca are in solution. Rimington (61) has reported the composition of phosphopeptone.

More than half of the ash is composed of calcium phosphate (19). Phosphate is the radical present in the largest amount, calcium second. Phosphorus has been reported present in milk in five forms (1) and again in eight forms (37). Calcium and magnesium are in combination with the casein to form calcium and magnesium caseinates. When casein is precipitated by acids, the calcium and magnesium are split off from the casein. When milk is heated some calcium and phosphorus are precipitated, the source probably being the colloidally dispersed calcium phosphates.

Lactose. The solubility of lactose and its properties may be found in the chapter on sugar. Lactose is caramelized by heat at rather low temperatures.

Proteins. The chief proteins of milk are casein, lactalbumin, and lactoglobulin. Enzymes are proteins. They have been mentioned. Casein is found only in milk. It composes about 3% of the total constituents of cow's milk and accounts for about 80% of the protein. The caseins from milks of different species are very similar. Lactalbumin composes about 0.5% of milk. The lactoglobulin of milk is reported in variable amounts in the literature, from about 0.05% to 0.2%.

Casein is a phosphoprotein. The phosphorus link (19) is stable at all *p*H ranges. In milk most of the casein is combined with calcium to form calcium caseinate. Some magnesium caseinate is found.

Various studies have shown that casein is composed of two or more fractions, the components differing in molecular weights (73), solubilities, composition, physical characteristics, and other properties. Warner (84) separated casein electrophoretically into α- and β-casein. The fractions were not electrophoretically homogenous under all conditions. The isoelectric values were reported as *p*H 4 to 4.1 for α- and *p*H 4.5 for β-casein. Linderstrom-Lang (44) thinks casein is made up of three fractions containing different proportions of phosphorus, each fraction being present in varying amounts. He also suggests that the amino acid content, particularly of tyrosine, varies in the three fractions. McMeekin and Polis (50) cite the work of Mellander. Mellander separated casein by electrophoresis into three components, α, β, and γ in the order of decreasing mobility. The α-casein contained 0.96% phosphorus (on the basis that casein contains 15.6% N); the γ-casein, 0.05%.

Casein is amphoteric, combining with both bases and acids. It is readily dispersed colloidally in weak solutions of alkalies, common alkaline salts, and some acids. It is insoluble in water. The isoelectric point (19, 62) is often given as *p*H 4.6, although various values have been reported.

Lactalbumin and lactoglobulin. When casein is precipitated the lactalbumin and lactoglobulin remain in the whey, and hence are often called the whey proteins. Lactalbumin (19, 62) contains no phosphorus, but its sulfur content is about 2.5 times that of casein. Lactalbumin forms a sol in water, dilute acid, dilute alkalies, and solutions of some salts.

The whey proteins (22) from various species show marked differences in electrophoretic composition and are characteristic for a given species. The composition (70) of the whey protein components is modified by three of the four methods used to prepare the proteins for electrophoresis. There are also differences in the mobilities and isoelectric points of the corresponding components.

The lactoglobulin (66) constitutes about 10% of the whey proteins. It is probably composed of two fractions.

The isoelectric point of lactalbumin is around *p*H 4.5. Lactalbumin is coagulated by heating in solution to about 70°C. Lactoglobulin is soluble in dilute salt solutions and is coagulable by heat.

The Fat Globules, Cream, and Butter

Fat. The fat of milk is found in globules, microscopic in size, suspended in the milk. They (62) vary in size from 0.10 to 22.0 μ. Most of the globules are less than 10 and average about 3 μ in diameter. The size of the fat globules varies: (*a*) with different breeds, being larger in milk from Jersey and Guernsey than in milk from other breeds; (*b*) with the lactation period, decreasing in size with length of the lactation period; and (*c*) with feed. Dry feed tends to decrease their size; succulent feed, to increase it.

The fatty acids of milk fat. Hilditch and Longnecker (30) state that oleic and palmitic acids compose about 50–55% of the total fatty acids of butter on a molar basis, and butyric, myristic, and stearic contribute 7–10% each. The saturated acids include butyric, caproic, caprylic, capric, lauric, myristic, palmitic, and stearic, with possibly some arachidic, behenic, lignoceric, and cerotic. The C_{18} unsaturated fatty acids are composed principally of oleic and linolic. There are also minor amounts of unsaturated fatty acids of molecular weight down to, but not below, $C_{10}H_{18}O_2$.

Variation in fatty acids. The percentage (21) of unsaturated and saturated fatty acids in the fat globules of milk varies with the feed of the cows, the unsaturated averaging higher in summer. The oleic and linolic acids (30) increase by about 4% (moles) with a parallel diminution in the butyric and stearic acids when the cows return to pasture. With increased age of the cow (30) the unsaturated acids increase at the expense of palmitic acid, which was lowered from 29 to 22–23% by weight of the total fat in the four years of observations made on milk from the same group of cows. Butter contains a high proportion of the low-molecular-weight saturated acids, *i.e.,* butyric, caproic, caprylic, and capric. The first acids of the acetic acid series are quite volatile with steam, the volatility decreasing with increase in molecular weight of the acid. Hence, when butter is heated several minutes, the percentage of the lower fatty acids may be decreased. The arachidic acid reported present by some investigators, if present, may come from the feed (62).

Creaming. The extent of creaming (62) depends upon the temperature, *p*H, fat content of the milk, and its degree of dispersion, and the fluidity of the system. Upon the fluidity of the system depends the probability of collisions of the fat globules. The collisons, or clumping, increase the tendency for fat globules to rise to the surface. As the larger clumps rise they carry many of the smaller globules to the surface. Clumping, therefore, aids not only the completeness of creaming, but also the rate, for the rate is more rapid when the fat particles clump quickly. The tendency to clump is greatest when the milk is cooled rapidly to 7–8°C, but if the fat globules become solid at the low temperature before creaming is allowed to take place the rate of creaming is retarded. Most cream is separated mechanically from the milk by centrifugal force. Although the cream can be separated to contain greater or smaller concentrations of fat, usually the fat particles left in the milk after this separation are those between 1 and 2 μ or less in diameter.

Sharp and Krukovsky (65) present evidence as follows: the clustering of fat globules is due to an agglutinin in the milk; this agglutinin is more strongely adsorbed, and hence exerts its greatest action on the solid or solidifying fat globules; it is not adsorbed on liquid fat globules, and consequently does not clump them; it is rendered inactive by heating to a high temperature; the agglutinating substance is concentrated in cream separated at low temperature and relatively absent in the corresponding skim milk; it is relatively low in cream separated at high temperature but present in the corresponding skim milk; the concentration of the agglutinating substance can be increased by separating the cream at a low temperature and then reseparating it to a higher fat content at a temperature at which the fat is liquid; the cream plasma obtained at the higher temperature is very active in agglutinating power; and, finally, the agglutinin has been isolated.

Cream is stabilized by proteins. The fat particles of cream are stabilized by the film of adsorbed protein substances surrounding the fat globules. The number of fat particles, according to Clayton (13), may be 1000 times greater in homogenized than in unhomogenized cream. This increases the surface area of the fat particles enormously so that a larger proportion of the proteins of the plasma is required for stabilizing films at the fat/liquid interface.

Whipped cream is both an emulsion and a foam. Both the fat particles and the air globules are stabilized by films of protein. In homogenized cream so much protein is required at the fat/liquid interface that not enough is left in the plasma to stabilize the air bubbles at the liquid/air interface; hence homogenized cream seldom whips.

Factors that affect the whipping quality of cream. The protein film, which increases the stability of the whipped cream through its surface denaturation at the air/liquid interface, the size of the fat particles, the fat content, the viscosity of the cream, the acidity, the temperature of whipping, and the addition of sugar are important factors in the whipping of cream. For a stable foam there must be sufficient protein to form the stabilizing film around the air bubbles, and the fat particles must clump, adding stiffness and stability. As the fat particles clump at the liquid/air interface (59), or within the liquid, the increased rigidity that they give the foam permits inclusion of more air bubbles and extension of the films with the result that the dryness of the foam is increased. See Fig. 46. Larger fat particles clump more readily and thus give more structural support. This is why cream from milk containing larger fat particles (Jersey and Guernsey breeds) whips more quickly than cream from other breeds which contains smaller ones.

Cream whips better with an increasing fat content up to 30%.

Dahlberg and Hening (17) found that increased viscosity increases the whipping properties of cream, but the lowering of the surface tension does not improve the whipping qualities. Aging increases the viscosity of the cream and hence its whipping properties. Pasteurization has a detrimental effect on whipping quality.

Low temperatures (4), 7–8°C (45°F) or lower, favor the whipping of cream as they induce clumping of the fat particles. Above 10°C (50°F) the decrease in stiffness of whipped cream is in direct ratio to increase in temperature, so that 30% cream will not whip at 22.2°C (72°F).

Babcock (4) found that acidity up to 0.3%, at which sour taste is evident, had no effect on whipping quality. If acid was added in excess of 0.3%, whipping quality decreased, whether added to fresh or aged cream, when the amount added began to curdle the cream.

The addition of sugar to cream either before or after whipping (4) was found to decrease the stiffness of the cream. For each 2 teaspoons (about 8–9 grams) added to 100 cc of cream, the stiffness decreased 4 points on the stiffness scale. Adding the sugar before whipping the cream decreased the volume obtained and increased the whipping time. The addition of sugar, by preventing denaturation of the protein at the air/liquid interface, tends to lessen the stiffness and stability of the cream.

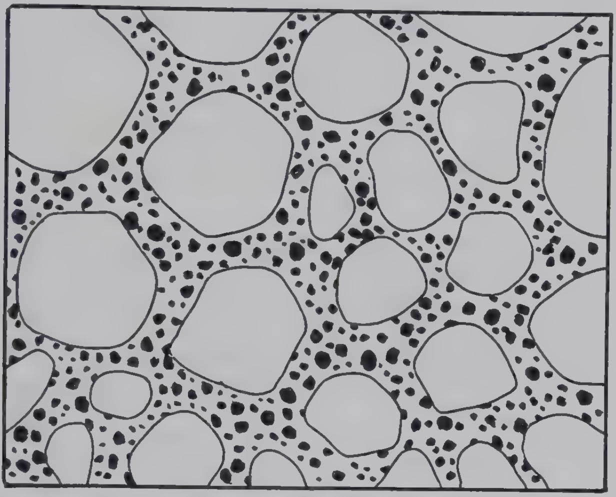

FIG. 46. Diagram of a cross section through whipped cream. Fat globules of the cream are shown as small black spots. Magnification about x 180 (*Rahn*).

Cream of 40% or higher fat content (18) is sometimes frozen in order to carry excess cream from seasons of surplus to periods of shortage. Freezing causes a great deal of the fat to separate, which reduces the whipping quality of the cream. The thawed cream is homogenized and mixed with fresh cream for use in ice cream.

Butter. Butter may be churned from sweet or sour cream, the flavor of that from sweet cream being milder.

Butters with satisfactory flavor and aroma (51, 58) contain considerable quantities of acetylmethylcarbinol plus diacetyl. The acetylmethylcarbinol in a pure condition is odorless, but it is oxidized by the action of citric acid fermenting streptococci to diacetyl, which in concentrations of 0.0002–0.0004% gives butter a characteristic aroma. In a butter culture a portion of the citric acid is broken down to acetylmethylcarbinol (8).

Tests for butterfat. The adsorbed films surrounding the fat globules may be destroyed by the addition of acid or alkali. The Babcock test, or some modification of it, is usually employed in estimating the fat content of milk and cream. In the Babcock test, acid is used for liberating the fat globules; in the Höyberg test alkali is used.

Chemical and Physical Properties of Milk

Reaction of milk. Freshly secreted milk has a *p*H of approximately 6.6. With loss of CO_2 from the milk, the titratable acidity decreases for a time in milk exposed to the air. Confined milk does not show as great a decrease in titratable acidity, owing to a smaller loss of CO_2. Fermentation brings about increased acidity.

Effect of heating milk on its acidity. When milk is heated to temperatures near or above the boiling point the titratable acidity at first decreases owing to loss of CO_2, then increases. Whittier and Benton (87) report that the continuous increase in hydrogen-ion concentration and the later increase in titratable acidity are due to the formation of acid from the constituents of milk. The conditions for this increase in acidity are discussed later.

Surface tension of milk. The surface tension of milk (62) is approximately constant, 56–59 dynes/cm at 20°C or below. With increase in temperature the surface tension is decreased to 42–45 dynes/cm at 45–60°C. Foams of milk are less stable at lower temperatures since the films are thicker and drain more rapidly. At higher temperatures the films are thinner, drier, and more stable.

The "scum" of heated milk. When milk is heated in an open pan, a scum or skin forms over the surface of the milk. At first this skin is rather thin and mobile but is gradually altered so that it becomes tenacious and tough enough to be removed with a stirring rod or spoon. It is said to consist of coagulated albumin and globulin. If this scum is removed from boiled milk the losses, according to Andross (2), may be nearly 13% of the solids of the milk; they include about ¾ of the albumin, ¼ of the fat, ⅛ of the protein, and nearly ⅙ of the ash.

When foods are cooked in milk the milk not only foams readily but the scum tends to hold the steam formed, and so the milk "boils over" readily.

Gelation of milk. A caramel pudding of thickened consistency for serving is made as follows. A can of condensed milk is boiled 3 hours or longer. The contents of the can are then cooled. When opened it has the consistency of pudding and can be sliced.

Acid is also used by the housewife to produce thickening in condensed milk. About ½ cup of lemon juice is stirred into the contents of a can (about 1½ cups) of condensed milk. The mixture thickens to a consistency to use for a pudding or pie filling. It may be thinned with water to any desired consistency for topping for puddings, gingerbread, etc. The reason for the thickening is explained partly in the preceding section, partly in Chapter 1, but complete knowledge of what happens to the protein molecule during coagulation, and the part that acids, salts, and sugar have in this process, is lacking.

Coagulation of Milk

The theory of denaturation and coagulation has been discussed in Chapter 1. Coagulation or clotting of the milk proteins by rennet, acid, and heat will be considered. Since casein comprises about 80% of the protein, the clotting of milk is, in general, principally affected by the behavior of the casein.

Rennet coagulation. Rennet is an extract usually obtained from the nner lining of the stomachs of calves and lambs. Rennet coagulates milk, the manner of its action not being fully understood. According to Davis (20), commercial rennet contains enzymes capable of at least four distinct actions: (*a*) the adsorption of rennet on casein, (*b*) change in state of casein, (*c*) the precipitation of the casein, and (*d*) subsequent proteolysis. A very small amount of rennin is capable of coagulating a large amount of milk. At favorable or optimum hydrogen-ion concentration for clotting, 1 part of fairly pure enzyme preparation is able to coagulate 3,000,000 or more parts of milk.

Factors affecting coagulation by rennin. Several factors influence the activity of the rennin in bringing about clotting of the casein: (*a*) temperature for rennin action; (*b*) heating the milk before the addition of rennin; (*c*) hydrogen-ion concentration; (*d*) concentration of casein, calcium, and phosphate ion; (*e*) character of cations used for coagulation; and, (*f*) factors that affect the rennin itself.

The optimum temperature of coagulation (62) by calf rennin is about 40–42°C. By optimum is meant the temperature at which clotting takes place most rapidly for a given concentration of rennin and milk. No clotting occurs below 10–15°C or above 60–65°C. The clot is soft at low temperatures and tough and stringy at high ones.

If the milk is boiled and then cooled before the rennin is added, the rate of coagulation is retarded and a much softer, more flocculent clot is obtained. Pasteurization retards clotting by rennin, but not to the extent that boiling does. The optimum hydrogen-ion concentration for rennin activity has been reported to lie between *p*H 5.99 and 6.40. When the reaction is sufficiently alkaline clotting does not occur. This can be shown by adding a little soda to the milk before the rennin is added.

Coagulation of milk by acid. Kruyt (39) states that some proteins are not sufficiently hydrated to be stable by hydration alone. He cites casein as a protein "which can exist either in acid or in an alkaline solution, but does not dissolve in water, with the consequence that the sol ordinarily flocculates when neutralized." Either the acid produced during fermentation or acids added to milk precipitate the casein. The casein is least soluble at its isoelectric point *p*H 4.6. If enough acid is added to lower the *p*H below 4.6, casein salts, such as casein chloride or casein lactate, are formed. If these salts are soluble, the casein goes into solution. Hence the largest yield of precipitated casein is near the isoelectric point.

Heat coagulation. Ordinary heating of milk in food preparation does not bring about coagulation. Colostrum, because of its very high globulin content, will coagulate by ordinary heating and is sometimes used to make pudding, somewhat like custard, but without the use of eggs. Davies (19) states that partial coagulation is shown by the "skin" formed on the surface of milk when it is heated.

Casein. Casein is relatively stable to heat, but it can be coagulated. The time (62) required is about 12 hours at 100°C, 1 hour at 135°C, and 3 minutes at 150°C. The time for individual samples of milk to coagulate at the high temperature varied considerably, owing to differences in salt content and of other constituents.

Sommer and Hart (67) in studying the milk from individual cows found that some milk heated to 136°C coagulated in 90 seconds whereas other milk did not coagulate in 20 minutes. In general, the decrease in time of coagulation (86) with increase in temperature has been shown to be of a logarithmic nature. The rate of coagulation also depends upon the concentration of the casein. Holm, Deysher, and Evans (34) found that milk evaporated to twice its solids-not-fat content, and thus a higher casein concentration coagulated with 10 minutes' heating at 131°C.

Forewarming. The improvement in resistance to heat coagulation by forewarming is rapid up to 90°C, but above 90°C the change is very small. If the variable (43) is time, instead of temperature, improvement in coagulation is noted by forewarming up to 30 minutes at 95°C.

Lactalbumin and lactoglobulin are not coagulated by rennin. When casein is precipitated by acid near its isoelectric point, the lactalbumin and lactoglobulin remain in the whey. Both proteins are coagulated by heat. Rowland (63) found that the relative increase in rate of denaturation for each 1°C rise in temperature between 63° and 75°C was constant, the temperature coefficient being 1.5. The amount of these proteins coagulated at a given temperature varies somewhat with the particular sample of milk. This is shown in the following results of Rupp (64) and Rowland (63). The sample of milk used by Rowland contained 0.3477% of casein nitrogen and 0.0766% of albumin and globulin nitrogen. The amounts given were coagulated in 30 minutes.

RUPP'S RESULTS

TEMPERATURE °C	ALBUMIN COAGULATED %
62.8	0.00
65.6	5.71
68.3	12.75
71.1	30.87

ROWLAND'S RESULTS

TEMPERATURE °C	ALBUMIN AND GLOBULIN COAGULATED %
63.0	11.8
67.2	20.7
70.0	28.3
75.0	67.5
80.0	83.4

The role of salts: In heat coagulation of milk, the milk salts play an important role. The effect of salts upon the coagulation of milk has been the subject of many investigations (52, 68, 86). A perusal of these publications indicates that the investigations are not complete. However, these studies emphasize the general role of salts in precipitating colloids and the coagulation of proteins as discussed in Chapter 1, in that the charge of the ion, the particular salt, its valence, its concentration, the manner of adding, and the concentration of the colloid are important factors in the result obtained. There must be a balance between the calcium and magnesium with the citrates and phosphates. However, since the *p*H and concentrations of the various constituents of milk vary from sample to sample the results obtained often apply to specific conditions. It has been found that the citrate ion is a good peptizer of egg proteins. The addition (62) of 0.2–0.6% of $CaCl_2$ coagulates milk at 45–65°C although larger or smaller concentrations do not coagulate it. Under some conditions (52) the addition of a small amount of calcium salts stabilizes whereas a larger concentration decreases the stability of the milk to heat. These same workers found that the addition of phosphate, citrate, or carbonate to the fresh skim milk (*p*H above 6.5) lowered its stability. They also report that milk is very sensitive to *p*H changes in two ranges, *i.e.,* *p*H 6.4 to 6.2 and 5.4 to 5.2.

Heat coagulation of casein endothermic. Leighton and Mudge (43) have shown that an endothermic reaction accompanies the appearance of visible curds when milk is coagulated by heat. This is accompanied by precipitation of calcium and magnesium as phosphate and citrates.

The endothermic reaction is characteristic of reactions that are accelerated by increase in temperature. Similar reactions are noted in the cookery of eggs and meat.

Coagulation of milk by cooking vegetables in it. Fresh milk is seldom coagulated by heating for home use. The temperature attained in ordinary heating is not great enough to cause coagulation, nor is the milk heated for the long period required for coagulation at boiling temperatures. But with the addition of other foods to milk in food preparation, coagulation often occurs with a very short period of heating. The factors bringing about this coagulation undoubtedly include the *p*H of the vegetable, the tannin content as well as the salt content of the vegetable and possibly other factors, which upset the stability equilibrium of the milk. Usually the coagulation of the milk can be prevented by the addition of a small amount of $NaHCO_3$.

Milk usually does not curdle when cabbage, chard, spinach, or cauliflower is cooked in it, but it is likely to curdle when asparagus, string beans, peas, and carrots are cooked in it. The acidity of some vegetables is greater than that of others. The tannin content varies with different vegetables and with the same vegetable grown in different soils and seasons. Tannin is a dehydrating agent and brings about denaturation of hydrophilic sols. Kruyt (39) states that tannins do not bring about coagulation of the protein in an alkaline medium. It is rather interesting that the vegetables that usually foam the most when cooked in water are the ones that have the greatest tendency to coagulate milk.

Cooking meat in milk. Sliced ham, floured and seared pork chops, fish, and other meats are sometimes baked or cooked in milk. It is desirable to prevent curdling, as the meat is less attractive in appearance when this occurs. Among the causes of clotting are the temperature at which the meat is cooked, the salt content of the food cooked in the milk, the manner in which the milk is added to the meat, and the reaction of the milk.

The salt content of the food cooked in the milk influences the coagulation, and this combined with the heating, the temperature of heating, and the acidity developed are sufficient to cause curdling. Curdling is more likely to occur when the meat cooked in the milk is salted and cured than when fresh meat is used.

If a portion of the milk is added to the meat when cooking is first started and the rest of the cold milk added gradually to the meat during the cooking period, curdling is less likely to occur. The addition of acid ingredients or foods such as prepared mustard or apples increases the tendency to curdling. Evaporated milk has less tendency to curdle than fresh milk, perhaps because of the previous heating. The curdling can be prevented by the addition of $NaHCO_3$ to the milk, which increases the alkalinity.

Tomato soup. When tomatoes are combined with milk to make cream of tomato soup, coagulation may occur. The acidity of tomatoes varies somewhat, but is about pH 4.4 to 4.6. If the amount of tomato added to the milk is great enough to lower the pH of the mixed milk and tomato to 4.8 to 4.6, the casein is precipitated without heating. This may happen if the milk is already fairly acid.

Curdling is less likely to occur if the tomato is added gradually; if hot tomato is added to cold milk; and if the milk and tomato are heated together for as short a time as possible. Sometimes curdling occurs with all conditions unless soda is added. At other times curdling does not occur with any method of combining.

Fruits and milk. When cream is added to fruit, clotting often occurs. This is usually due to the acidity of the fruit, but may also be due to an enzyme in it. Raw pineapple contains an enzyme, bromelin, that brings about clotting of milk. However, the pineapple juice also brings about peptization, for after a time the clot formed is less firm and the flavor is similar to that of peptized meat.

CHEESE

Classification of cheese. Cheese may be classified according to (*a*) the method by which the curd is produced, *i.e.,* acid or rennet coagulation; (*b*) the source of the milk, from cow, sheep, or goat; and (*c*) the texture and consistency of the cheese, *i.e.,* whether soft, semihard, or hard. Many other classifications are possible but none of them are entirely satisfactory.

Doane and Lawson (24) list and describe nearly 300 cheeses. They state that there are probably about 18 distinct varieties of cheese.

For purposes of discussion, Rogers classifies cheese as follows:

- *Soft*
  - Unripened
    - Cottage
    - Cream
    - Neufchâtel
  - Ripened
    - Ripened by molds
      - Camembert
      - Brie
    - Ripened by bacteria
      - Limberger
      - Liderkranz
- *Hard*
  - Semihard
    - Ripened by molds
      - Gorgonzola
      - Roquefort
      - Stilton
    - Ripened by bacteria
      - Brick
      - Munster
  - Very hard
    - Without gas holes
      - Cheddar
      - Edam
      - Gouda
    - With gas holes
      - Emmenthal
      - Swiss
      - Parmesan

Composition of cheese. From the standpoint of quantity the principal constituents of cheese are casein, fat, and water. In addition it contains various salts, and unless heated to pasteurization temperatures various organisms such as bacteria and molds. Different types of soft cheese may contain from 40 to 75% water; hence this type does not keep long. Hard-type cheeses usually average 30–40% moisture. The soft types may contain from 13 to 21% of protein and from 0.5 to 50% of fat. Hard types contain 20–45% protein and 19–40% fat.

Coagulation of milk for cheese. Coagulation may be brought about by rennet or acid. Rennet-formed curds are more elastic, the acid ones more sticky. In acid-formed curds more of the calcium salts are split off from casein, forming calcium chloride which is soluble in the whey. Rennet-coagulated cheeses (49) of cheddar types retain about 80% of the calcium of milk; soft cheeses retain about 20%.

The temperature for coagulation varies with the type of cheese desired. n general, the lower the temperature the softer the curd. Curds formed at 21–25°C are used for some soft cheeses. Cheddar cheese has a firmer curd, and the milk is brought to 30°C before the starter and rennet are added. Temperatures as high as 48°C may be used for some cheese, the curd produced being distinctly tough and somewhat rubbery and elastic.

A secondary heating of the curd is necessary with most hard and semihard cheeses. Making Emmenthal involves heating to about 55–58°C. This heating hastens the driving of whey from the curd, changes its texture, often alters the bacterial flora, and checks or wholly stops rennet action. Various physical changes take place during this period, the curd becoming tough, firmer, and rubbery.

Ripening of cheese. In the process of ripening, chemical and physical changes occur in the cheese. It loses its tough, rubbery qualities and becomes soft and mellow, sometimes almost crumbly. During this change as much as 50% of the nitrogenous constituents may be converted to soluble forms, though the average for hard cheese is 30%.

Volatile and other acids (31), which play an important role in the distinctive flavor of different cheeses, develop during this period. Lipolysis occurs to a greater extent in the semihard types, especially those of the blue type, than in the hard cheeses.

Ripening is slower at lower temperatures and more rapid at higher ones. Not only enzymes of the milk, if the milk has not been heated to a temperature to destroy the enzymes, but also bacteria aid in ripening of the cheese and hydrolysis of the proteins. Some bacteria, such as lactic acid bacteria, produce enzymes that split the protein. More hydrolysis occurs in the softer center of hard cheese than near the rind. Salting affects the rate of ripening by delaying bacterial growth, the proteins of cheese with more salt becoming soluble at a slower rate. Salt penetrates slowly from the rind to the center and aids in drying the cheese. Changes in the fat in the interior of most cheese are usually negligible.

For the growth of molds and aerobic bacteria, holes must be punched in the cheese to allow oxygen from the air to penetrate.

In the early stages of ripening, Emmenthal and Swiss cheeses are soft and become elastic. It is during this stage that the holes or "eyes" are formed from production of gas, principally CO_2, if ripening is normal, but with more hydrogen in abnormal or early ripening. If the cheese becomes too firm before the formation of holes is complete, checks and cracks appear in the cheese.

Processed cheese. "After the rind is removed, the cheese is ground, a small quantity of water and an emulsifier, usually sodium citrate, are added, and the mass is heated with constant stirring until it becomes fluid. The emulsion is run into forms, which in many cases are boxes lined with tinfoil, in which it is sold. The cheese hardens quickly and, as the wrapping adheres closely, there is no trouble from molds. Moreover, as the temperature is high enough to constitute pasteurization, most of the bacteria are killed and the enzymes destroyed, so that ripening is stopped. In this process, much of the original character of the cheese is lost; but, in spite of this objection, the advantage of the package is so great that a large part, possibly one-third, of all the cheese made in the United States is sold in this form" (62).

An emulsifier is necessary to prevent the separation of the fat (77). Salts permitted as emulsifiers by the Food and Drug Administration in cheese are given in the chapter on emulsions.

Loaf cheese. Blending (62) is used extensively for Cheddar and Swiss cheese. In this process the cheese is ground and heated in steam-jacketed kettles, 60–70°, and then poured into molds. In the initial heating separation of the fat occurs; but with longer heating the casein becomes plastic and encloses the fat. Further agitation causes the mass to become the consistency of heavy cream. At this time it is poured into the molds.

Cheese spreads. The term cheese spread may be applied to any packaged form of cheese that can be easily spread with a knife at ordinary room temperature. Templeton and Sommer (78) name the types on the market as: (*a*) cream cheese, mixed with pickles, olives, etc., (*b*) processed cheese of such age and moisture content as to be "spready," and (*c*) processed cheese with concentrated whey or skim milk powder added and of such fat and moisture content that the mix will spread easily. Since the composition is quite different from cheese, as defined for Food and Drug regulations, the product cannot be sold as cheese. Actually it is sold under proprietary trade names. The desirable spreading qualities may be due to the moisture content or the fat content or both.

The Use of Cheese in Cooked Products

All the factors that affect the plasticity of the cheese when heated for blending, *i.e.*, the degree of ripening, the acidity, and method of manufacture, also affect its blending properties with other ingredients in such dishes as rarebit, cheese soufflé, and macaroni and cheese. To these factors may be added the extent of drying, for the cut or grated surface of cheese may dry rather extensively.

Factors affecting cooking quality of cheese. Cream cheese, which has a high moisture content, combines readily with sugar, eggs, milk, and sauces for food products. Processed cheese, with its emulsifier and special treatment, also combines readily with sauces for macaroni, potatoes, and soufflés. Cheddar cheese may or may not possess excellent cooking qualities.

Personius et al. (57) found that Cheddar cheese of normal fat content shows a progressive improvement in cooking quality over a 12-month period of ripening and a progressive increase in the amount of soluble protein. This improvement is more rapid in a cheese of high moisture content. In general, cheese ripened in hermetically sealed cans showed a more rapid improvement in cooking quality than cheese from the same curd ripened in a Daisy. A cheese of low fat content has conspicuously poor cooking quality. Relatively high temperatures and long periods of heating tend to increase matting, stringing, and toughening of the cheese as well as increasing the separation of the fat.

The blending quality of the cheese appeared to be affected by the acidity and hydrogen-ion concentration. Between *p*H 5.0 and 5.6 the tendency for stringiness occurred; the cheese separated from the liquid in which it was heated in curd-like particles at *p*H 4.0 to 5.0; the cheese dispersed readily at pH 5.8 to 8.0. It is suggested that removal of the calcium by phosphates in the buffer solution had an effect on the increasing dispersion.

Rarebit. Wills (69) found that a Longhorn Cheddar cheese ripened 82 days or until considerable of its nitrogenous constituents were converted to soluble forms blended very readily with a sauce to make rarebit. Insufficiently ripened cheese of similar composition failed to combine with the white sauce, even after 25 minutes beating, and produced a rubbery, stringy, tough rarebit. Temperatures of 40–50°C are usually preferable to 60–70°C for blending cheese with sauce.

Cheese soufflé. If the beaten egg yolks are added to the white sauce before the cheese two benefits result. They serve to help cool the mixture before the grated cheese is added and also aid in emulsifying the fat of the cheese. For the same reason beating with a rotary egg beater as the cheese softens is a good method of blending since it more efficiently divides the cheese, thus increasing the surface area for emulsification.

Hoffman (69) found that drying of the cheese had a detrimental effect on the smoothness, consistency, and flavor of cheese soufflé. If the cheese had not become too dry, it could be improved by soaking in a portion of the milk.

Processed or packaged cheese usually combines particularly well with white sauce and egg yolk, because of its added water content and the emulsification of the fat.

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MILK AND MILK PRODUCTS

Cream of Tomato Soup

Experiment 35.

To determine the best method of combining ingredients in making cream of tomato soup.

Use:

Milk	¼ cup	60 grams
Tomato juice	¼ cup	60 grams
Flour	½ tablespoon	3.5 grams
Butter	½ tablespoon	7 grams
Salt	⅛ teaspoon	

1. Make a sauce of the milk, flour, and butter; add cold tomato juice, and heat.
2. Repeat 1, but add hot tomato juice to the sauce.
3. Make a sauce of the tomato juice, flour, and butter. Add to the cold milk. Heat.
4. Repeat 3, but add the tomato sauce to the hot milk. Does the addition of flour lessen the tendency to curdle? Can cream of tomato soup be made without the addition of soda?

For additional experiments, repeat the tests with reconstituted evaporated, frozen, dry skim milk (NFMS), and/or whole milk solids. The average weight of a tablespoon of dry milk is about 8 grams.

Cooking Vegetables in Milk

Experiment 36.

To determine the effect of cooking vegetables in milk. Use green string beans, asparagus, or carrots.

1. To ¾ cup of milk add ½ pound of string beans. Cook until tender. The beans may be shredded in long strips to hasten cooking.
2. Repeat 1, but have the milk boiling before adding the vegetable.
3. Repeat 1, but add the vegetable to one-third of the boiling milk. Add the remainder of the milk in small portions during cooking.
4. Repeat 1, but add 1/32 teaspoon of soda to the milk.
5. Repeat 1, but use cabbage or cauliflower.

Does any curdle? Is there any difference in the size of the curds formed in cooking by the different methods? Why may one vegetable cause the milk to curdle but another vegetable not cause curdling? If you wish to add milk for seasoning to a vegetable like asparagus or green beans, how would you add it to prevent curdling? Is it desirable to use soda?

Ham Baked in Milk

Experiment 37.

To bake ham in milk.

1. Use mild-cured ham in 1-inch slices. To ½ pound of the ham 1 inch thick add 1 tablespoon of medium-brown sugar, sprinkling it evenly over the ham. Add ½ cup of milk, and bake at 125°C (257°F) until tender. The size of the dish should be such that the milk barely covers or just reaches the top of the ham.
2. Repeat 1, but prewarm the milk by boiling it before adding to the ham.
3. Repeat 1, but add only one-third of the milk. After baking 30 minutes add the remaining milk in small portions at intervals of a few minutes.
4. Repeat 1, but add 1/32 teaspoon of soda to the milk.
5. Repeat 1, but use evaporated milk. Dilute ¼ cup of evaporated milk with ¼ cup of water, and add this diluted milk to the ham.
6. Repeat 1, but bake the ham at 175°C (347°F) until tender.

In which experiments does the milk curdle? Are some more curdled than others? What is the effect of a higher temperature upon curdling? Compare the flavor of ham.

The series may be repeated, omitting the sugar and using pork chops or fish instead of the ham. There is less tendency to curdle with the fresh meat.

Welsh Rarebit

Experiment 38.

To determine the most satisfactory method of combining ingredients for Welsh rarebit.

1. Prepare a white sauce, using ½ of the following ingredients:

Butter	1 tablespoon	14 grams
Flour	1 tablespoon	7 grams
Mustard	½ teaspoon	
Salt	½ teaspoon	2 grams
Milk	¾ cup	183 grams

Remove from the heat and divide into two portions. While still hot (heat again if necessary), to one portion add 28 grams of grated cheese. Stir with a spoon or beat with a rotary egg beater until the cheese is melted and blended with the sauce. Place in top of double boiler and heat slowly to serving temperature. Use the second portion of the sauce for 2.

2. Repeat 1, but cool the sauce to 40°C before adding 28 grams of grated cheese.

3. Use ½ of the ingredients listed above, omitting the flour and adding 1 egg yolk (48 grams). Heat until the mixture thickens. Cool to 40°C, then add 28 grams of grated cheese, following directions under 1.

4. Repeat 3, but add the cheese to the milk. Heat in a double boiler until the cheese melts. Add the beaten egg yolk and cook until the mixture thickens.

Cheese Soufflé

Experiment 39.

To determine a satisfactory method of combining and baking cheese soufflé.

Recipe:

Butter	3 tablespoons	42 grams
Flour	2 tablespoons	14 grams
Milk	½ cup	122 grams
Egg yolks	3	54 grams
Cheese, grated	½ cup	56 grams
Salt	½ teaspoon	
Egg whites	3	90 grams

Directions for mixing:

Melt the butter. Add the flour and salt, and blend with the butter. Add the milk, and bring to boiling, stirring continuously. Remove from the stove, and beat the egg yolks thoroughly. Add egg yolks to the white sauce, and blend. Add the grated cheese, and mix thoroughly, using a spoon or a rotary egg beater. Fold in the stiffly beaten whites, and pour in baking dish buttered on bottom only.

A. The time of baking.

Prepare the whole or 1½ times the recipe (whatever amount is necessary for the size of baking dishes used). After mixing, divide, putting equal portions in three dishes. If possible set all three dishes in a large pan in the oven. Pour boiling water around the dishes and bake. Oven temperature 175°C (347°F). The time of baking may need to be varied, time given being suggestive, because the time will vary with the quantity of water poured around the baking dishes. The soufflés should be baked until little or no shrinkage occurs on removal from the oven.

1. Bake 40 minutes.
2. Bake 50 minutes.
3. Bake 60 minutes.

B. The temperature of baking.

Follow directions given under A. What modification of time will need to be made?

1. Bake one part at 160°C (320°F).
2. Bake a second part at 175°C (347°F).
3. Bake a third part at 190°C (374°F).

C. Compare baking the soufflés in dish surrounded by hot water and without water. Use temperatures and time found best under A and B. What modification of time will need to be made for those baked without water? Which conducts heat more readily, water or air?

D. The method and temperature of combining ingredients.

Bake at temperature and time found best under A, B, and C.

1. Follow directions for mixing under A.

2. Reverse the order and temperatures for adding the cheese and egg yolk. Add the cheese to the slightly cooled white sauce. Mix, then add the beaten egg yolks.

3. Add both the egg yolks and cheese to the slightly cooled white sauce. Mix.

Compare the volume, tendency to shrink, and texture of the soufflés. What temperature should the white sauce be when the cheese is added? Would this vary with different kinds of cheese, that is loaf, processed, and Cheddar? Would it vary with degree of ripeness or dryness of the cheese? What is a desirable method of making and baking cheese soufflé?

CHAPTER 11

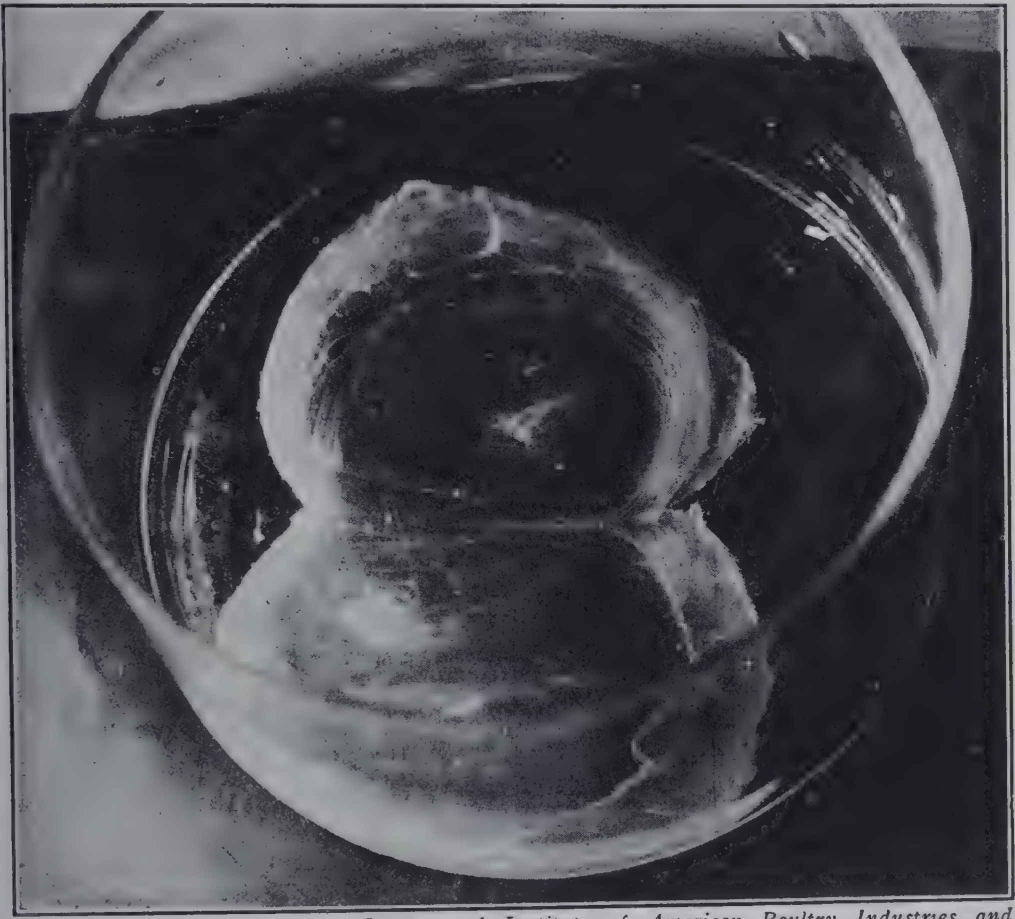
Eggs

Grading. By means of grading eggs are sorted according to size and quality factors. Quality factors include the (*a*) shell condition, (*b*) size of air cell, (*c*) yolk condition, (*d*) white condition, and (*e*) presence or absence of defects, such as blood spots. Interior quality is also determined after breaking out of the shell by other means than grading. Although candling (117) is not accurate, it is the best method available of grading eggs in the shell. The candler's opinion of interior quality is based largely upon the appearance of the yolk and air cell. To observe the egg in candling it is held, large end forward, against an opening in front of a strong light. In this position the egg is given a quick twist about its long axis. The candler notes the outline of the yolk, whether it can be clearly distinguished, its position (central or otherwise), and the ease with which it moves. It is obvious that the inertia of the yolk will be overcome more readily and show movement if a larger portion of the egg white is thin and watery than if it is viscous. Since the yolk comes nearer the shell in a more deteriorated egg its outline is more easily distinguished than in a fresh egg. The yolk color affects the visibility of the yolk shadow before the candle (124) and thus the grade into which the egg is placed. The size and depth of the air cell are noted and whether the air cell is fixed or tremulous.

U. S. Grades. There are four U. S. quality grades (20) for eggs with clean shells: AA, A, B, C. There are six weight classes: Jumbo, weighing at least 30 oz per dozen; Extra large, 27 oz; Large, 24 oz; Medium, 21 oz; Small, 18 oz; and, Pewee, 15 oz. The other classes of eggs are U. S. Light dirty (not more than ⅛ of the shell covered with dirt), U. S. Dirty, and U. S. Check or crack.

Structure. The shell constitutes the outer layer of the egg; on the inside of the shell is a thin semipermeable membrane made up of two layers, the inner and outer. The air cell at the large end of the egg is formed during cooling and by loss of moisture, the shrinking of the egg contents causing separation of the two membranes. The egg white is composed of three layers. The layer next the shell is a thin soft white, its relative proportion varying somewhat at time of laying. Next comes a layer of thick, viscous white; a narrow layer of thin white surrounds the yolk, separating it from the thick, viscous white.

Schaible, Moore, and Davidson (103) state that the thick, "firm white is of laminated structure, composed of concentric layers containing mucin fibers." If a freshly laid egg is broken into a large quantity of distilled water (the thick white having been slit with scissors on one side to remove the yolk) and allowed to stand, the mucin and probably some globulin are precipitated at the edge of the cut surface. Six or more sheets or layers, one over the other, can be distinctly seen (Fig. 47).

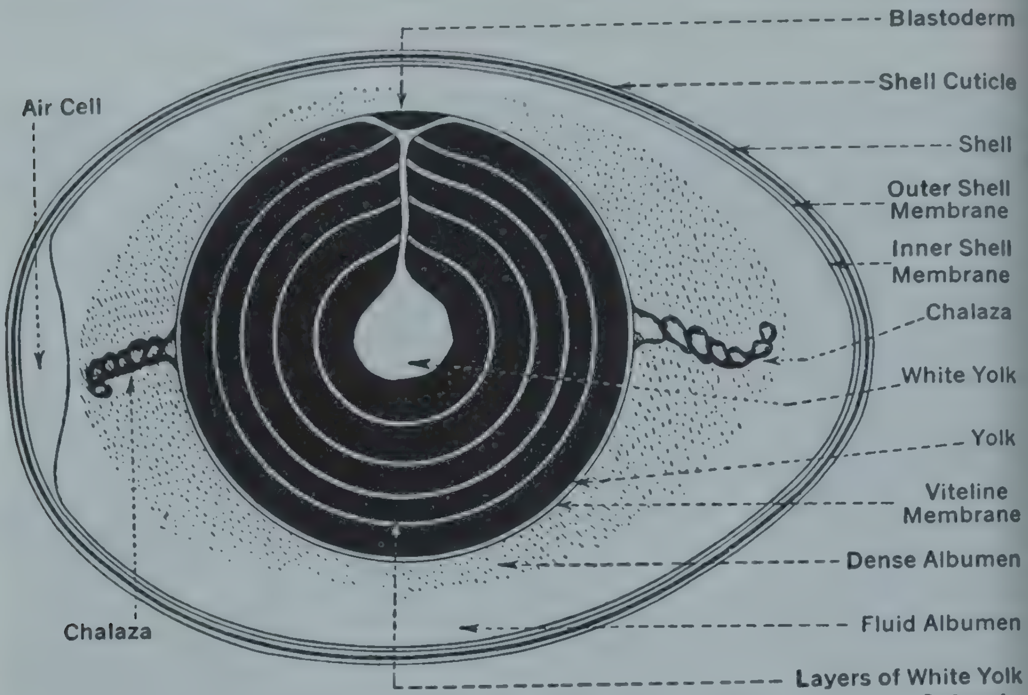


Courtesy of Institute of American Poultry Industries and P. J. Schaible, J. M. Moore, and J. A. Davidson, Michigan

FIG. 47. Showing the laminated structure of firm egg white, yolk removed.

The chalazae are dense, cord-like strands of white substance, mostly mucin, one on each side of the yolk, which anchor the yolk near the center of the egg and allow it to revolve. Being denser than other portions of the egg, they are not readily broken by beating, hence are often caught on the blades or wires of the egg beater.

The yolk is made up of layers, see Fig. 48. In some eggs the layers are distinct, in others scarcely discernible. The yolk is separated from the white by a yolk sac, called the vitelline membrane.



Courtesy of Institute of American Poultry Industries

FIG. 48. Diagram showing internal structure of an egg.

Composition. Cruickshank (25) and Mitchell (87) have both reported the composition of the egg. The shell, white, and yolk constitute 11, 58, and 31% of the egg, respectively, the variations in these proportions being slight in day-old eggs.

The shell consists principally of calcium carbonate, about 93.7%, with some magnesium carbonate, calcium and magnesium phosphates, 4.75% of organic matter, and 1.5% of water. The organic matter of the shell is found in the thin cuticle covering the egg, in the matrix in which the salts are embedded, and in the shell membrane.

The composition of the white (25) is 87.77, 0.05, 10.00, and 0.82% for water, fat, protein, and ash, respectively; the constituents of the yolk in the same order (87) are 49.0, 31.9, 16.7, and 1.9%. The total solids of the white are about 12.13%, of the yolk about 50.5%. Most American investigators report about 52% solids in the yolk. Sharp and van Wagenen (111) found that, when the yolk solids dropped to 46 or 47% through dilution by water from the white, the vitelline membrane ruptured when the egg was broken out of the shell. Both the white and the yolk (101) contain a small percentage of carbohydrate.

Color. *Shell.* The color of the shell is determined by inheritance, certain breeds laying white, others brown, and some foreign breeds blue shells.

White. Fresh egg white has an opalescent appearance. As the *p*H rises the white becomes clear and transparent. It may also have a greenish cast. This is attributed to the riboflavin present.

Yolk. The color of the yolk may vary from a very pale, almost white through deeper yellows to a deep orange. The coloring matter of the yolk according to Palmer and Kempsters' (92) study is xanthophyll. Carotene and cryptoxanthin are present in small amounts. The amount of pigment (95) deposited in the egg yolk varies under different conditions, but in general depends to a great extent upon the pigment content of the diet.

The pigment content of the yolk (125) is influenced to only a slight extent by heredity.

Abnormal colored yolks (125) are produced by some feeds. The capsanthin of pimento if present in excess of 0.35 mg per 100 grams of feed produces a red yolk, the depth of color being directly proportional to the concentration of the pigment in the feed. Some feeds, especially cottonseed meal, produce olive-colored yolks. Gish, Payne, and Peterson (42) suggest that olive-colored yolks have a much higher percentage of highly oxygenated carotenes (flavoxanthin-like xanthophylls) than do normal yolks from hens receiving the same feed. It is further suggested that the strongly adsorbed, oxygenated carotinoids may combine with egg yolk protein to produce the olive color. The abnormal colored yolks are not inedible.

Some attempts have been made to work out color standards to which the color of eggs may be compared. It is an advantage for bakers and mayonnaise manufacturers to obtain yolks of uniform color to insure uniformity of color for their products.

Odor and Flavor

McCammon, Pittman, and Wilhelm (76) found that the odor appeared to be influenced by both ration and method of handling. Sharp, Stewart, and Huttar (110) in studying the effect of packing materials on the flavor of eggs found that eggs with high *p*H, irrespective of packing material used, developed more undesirable flavor than eggs with lower *p*H. Packing materials were found to vary in transmitting flavors to eggs during storage.

Egg Quality

The term "quality" may be applied to eggs to denote their value from the nutritional, palatability, and culinary standpoint. As used herein it particularly refers to the cooking performance. It is commonly accepted that an egg of high quality is better for poaching, boiling, and frying. It is less commonly known that an egg of high quality produces a thicker, stiffer custard and a cake of greater volume, not only for angel cake, but also for cakes made with fat (100).

Measures for determining quality. *In shell.* Candling, the basis for commercial grading of eggs, has been considered.

On yolk. For use in research work Sharp and Powell (108) devised the yolk index for determining the quality of an egg. The height of the yolk, which is determined under standardized conditions, is divided by the width of the yolk. Haugh (50) and others proposed determining the amount of pressure required to break the vitelline membrane as an index of quality. At present the white instead of the yolk is used more extensively to determine egg quality, but the early work of Sharp initiated quality measurements.

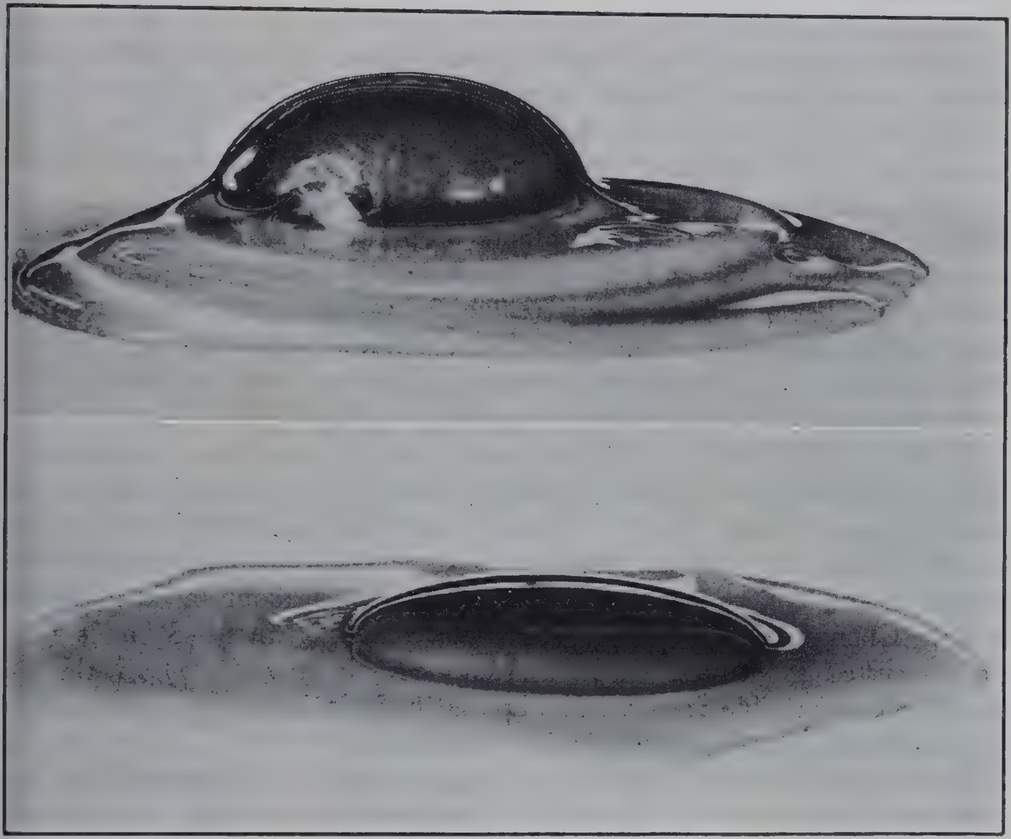
On the white. Holst and Almquist (58) suggest using the percentage of thick and thin white as an indication of egg quality. The thick and thin white are separated on screens. In variations of this method the thin white is removed with a pipet. Van Wagenen and Wilgus (124) have prepared a series of photographs of broken-out eggs as standards for comparisons of varying egg quality, the gradation being numbered from 1 to 5. The albumen index was proposed by Heiman and Carver (55). This index is obtained by dividing the height of the thick white by its width, both measurements being taken under standardized conditions. The Haugh (50, 51, 52) unit as an index of quality is determined from the height of the thick white and the weight of the egg. The last two measurements are the most commonly used for determining egg quality at the present time.

Production factors affecting egg quality. Just-laid eggs show rather wide variation; *e.g.,* there is considerable difference in the viscosity of the thick white. This is shown by observation and by determination of the albumen index and Haugh units. That this is influenced by breeding or is an inherited characteristic of the individual hen has been reported by several investigators (6, 125, 127). The thick white content (68) can be increased materially by breeding. The period of the laying cycle may affect egg quality. Sharp (107) states that, as the laying season advances, the freshly laid eggs of some hens become poorer in quality, possibly because of depletion of some factor. Most investigators have found that the feed does not affect the albumen index. Coles (23) indicates that both the climate and soil of England influence egg quality, poorer eggs being produced in sections with high humidity and with old rocky soil. The season of the year also affects the quality of the eggs. Hunter, van Wagenen, and Hall (61) found that the decrease in quality which started in March or April continued during the summer.

Deterioration of eggs. Sharp (106) states that "as soon as the egg leaves the hen it begins to decline in interior quality and the best we can hope to do is to retard these changes as much as possible. They cannot be stopped, they can only be retarded. An egg a week old may have deteriorated more in quality than an egg properly cared for which is a year old."

The changes produced by deterioration may be classed as physical and chemical.

Physical changes. The most important physical changes during deterioration of eggs are: (*a*) The thick white becomes less viscous and jelly-like, gradually changing from a white that stands up sharply when the egg is broken out on a flat surface to a thin watery white which spreads readily (see Fig. 49). (*b*) Water passes from the white to the yolk, increasing the size (107) and fluid content of the yolk, thus lowering the percentage of the yolk solids. In addition the vitelline membrane weakens and, if the deterioration has progressed far enough, breaks when the shell is opened. (*c*) If the eggs are not stored in a rather high humidity or oiled so that moisture loss is prevented, the air cell increases in size. (*d*) The egg may absorb foreign or off odors.



Century Photos, Inc.

FIG. 49. Showing standing-up quality of yolk and white of a fresh and a deteriorated egg.

Chemical changes. The chemical changes are those produced by (*a*) loss of water, (*b*) loss of CO_2, (*c*) change in *p*H, (*d*) the breakdown of protein brought about by alkaline hydrolysis, (*e*) an increase in the amount of loosely bound NH_3 in the yolk (107), (*f*) an increase in water-soluble or inorganic phosphorus (107), and (*g*) an increase in acid number of fat of the yolk (107).

Loss of water increases the solids content of the egg. From the culinary standpoint it is not a serious loss, unless other changes have occurred. Usually the humidity of the storage room is kept sufficiently high to prevent excessive moisture loss.

Loss of CO_2, which begins immediately upon laying, increases the alkalinity of the egg so that the *p*H of untreated eggs (109) rises rapidly. The higher the temperature, the more rapid is the loss of CO_2. Means of preventing loss of CO_2 from the egg are considered later. Wilhelm (128) reports that a 10% loss in albumen index during the first 24 hours after the egg is laid is related closely to the CO_2 loss as determined by *p*H. He also adds that "cloudiness of the albumen appears to be an indication of a low *p*H of the albumen, a high albumen index, freshness of the egg, and/or that the egg has been held at low temperatures. Albumen cloudiness may therefore be considered an indication of excellent interior quality."

Change in pH, as has been indicated, is closely related to loss of CO_2 from the egg.

Cause of deterioration. The results of but not the causes of deterioration are known. One group of investigators (30) expressed this as follows: "A major cause of the thinning of the white is inherent in the white itself." Balls and Hoover (6) state that there is no evidence of trypsin in egg white, and so deterioration is not brought about by a trypic enzyme. Changes in ovomucin (6, 29) and reduction in S—S bonds (78) are suggested as possible causes. Alkaline hydrolysis (105) of the egg proteins is a possible factor. If alkaline hydrolysis occurs, it is speeded up as the egg becomes more alkaline.

Changes produced by microorganisms. Sharp (107) states that not over 1–2% of clean eggs properly cared for are infected with microorganisms. The infection is much higher in eggs with dirty shells. Dirty shells (15, 86, 96) can be washed so that the eggs will keep as well as similar non-washed eggs, provided the bacterial infection from the dirt has not penetrated the shell before washing and/or if the washing water is kept clean. Extensive changes (from small spots, through mold spots to rotting) may occur in eggs infected with microorganisms.

Preservation of Eggs

No method of preservation improves the quality of eggs, but much can be done to maintain the quality at the time that treatment or processing is started.

The effect of temperature upon egg quality is shown vividly by Sharp (106) as follows: For eggs stored in air containing ordinary amounts of CO_2, at 80% humidity, the weakening of the yolk membrane was greater in 2 days' storage at 37°C than after storage for 5 days at 25°, 20 days at

16°, or 100 days at 2°C. Wilhelm and Heiman (126) found that temperature and time of storage affect egg quality as measured by the albumen index. A temperature of −1.1°C retards albumen index lowering markedly after a 30% loss has occurred. Temperatures of 10°, 15.5°, and 32.2°C (50°, 70°, and 90°F) are increasingly less desirable for storage.

Storing at low temperature. Since increase in temperature speeds the loss of CO_2 and liquefaction of the thick white, control of storage temperature is one of the most effective means of retarding deterioration. In commercial storage the temperature, humidity, and air currents are controlled, the last to prevent mold growth. The storage temperature is usually maintained at −1.8° to −1.1°C (29–30°F).

The majority of eggs are placed in low-temperature storage during March, April, May, and June. More than half of the annual supply is laid during these four months. Withdrawal of eggs from storage usually begins in August, reaches its peak about November, and the supply is generally exhausted by January.

CO_2. Preventing loss of CO_2 is another means of preserving egg quality. In low-temperature storage chemical control of the atmosphere may be practiced by maintaining a definite concentration of CO_2.

At room temperature (105) it takes approximately 10–12% of CO_2 to hold the white at *p*H 7.6, but near the freezing point about 3% in the atmosphere is sufficient.

Thermostabilization. Funk (40) reviews the literature on the use of heat to improve the keeping quality of shell eggs. The eggs are heated in the shell in water or oil at times and temperatures just sufficient to devitalize fertile eggs, to stabilize the thick albumen, and to pasteurize the shell eggs. Funk states that the process has merits, stated above, and disadvantages. The disadvantages are that the white requires more time for whipping and does not produce as large a volume of foam. In addition, the incidence of stuck yolks (yolks sticking to shells) is increased by the process.

Oil treatment. Egg quality can be preserved by dipping the eggs in a special colorless, tasteless mineral oil of the right viscosity. To be of value, the eggs should be oil treated before too much CO_2 has escaped (41, 111). Grant (45) states that the temperature of the eggs should be between 10° and 21°C, that of the oil at 21–27°C. No beads of oil are left on the egg, and the eggs are placed in a cooler within 30 minutes after dipping. He also states that special effort is required to keep the machinery and oil sanitary.

Water glass storage of eggs (46) is not very satisfactory.

Freezing. Egg products preserved by freezing are liquid egg magma (white and yolk mixed), whites, or yolks. Pasteurization (48, 93, 130) is one of the great improvements in the treatment of liquid egg products for freezing or drying. The benefits of pasteurization are improvement in keeping quality (129), twice as long for yolk and white at household refrigerator temperature, a great reduction in viable bacteria, and destruction of possible pathogenic bacteria. Pasteurization at too high a temperature or for too long a time results in heat injury to the liquid egg product. Bacteria are destroyed more easily in the white than the yolk (129). This is important for egg white proteins are heat denatured at a lower temperature than the yolk proteins. Stewart (120) suggests the following temperatures and holding times for pasteurization: liquid whole egg and liquid yolk at 61°C for 3 and 2 minutes, respectively, and liquid white 56.7°C for 0 minutes.

Freezing does not alter appreciably the physical characteristics of the egg white, *i.e.,* after defrosting the white is similar to the unfrozen white and can be used in the same way.

The egg yolk upon thawing does not have normal fluidity but forms a pasty, viscous, sometimes leathery gel. Sometimes it is so viscous that it does not blend well with sugar, milk, or other ingredients. Whole egg does not form as viscous a gel as the yolk. The extent of gelation (4) may be lessened by longer mechanical mixing of the egg magma or putting it through a colloid mill; by addition of salt, sucrose, dextrose, honey; or a combination of salt and sugar to egg yolk or egg magma. The maximum degree of gelation is reached in 60–120 days' storage at −21° to −18°C (4). Pasteurization may aid in preventing the gelation. Miller and Winter (83) found that frozen and thawed pasteurized eggs were more viscous than fresh eggs, but less viscous than non-pasteurized eggs.

Dried egg. Dried egg powders like the dried milk powders have been produced in large quantities since World War II. An approximate production estimate (17) for 1951 follows: whole eggs, 11,200,000 pounds; yolks 3,500,000; and whites 2,880,000 pounds.

Egg powders may be prepared from the whole egg, the egg yolk, or the egg white. Most of the commercial powders are spray dried, although considerable egg white is dried in trays or as a film on a continuous belt (115). Among the advantages of using dried egg are: (*a*) the conservation of space; (*b*) only the dried product can be incorporated in prepared mixes that are stored for baking; and (*c*) ease in use. The largest tonnage (115) of the dried egg powders used in mixes at present is the yolk. It is used in doughnut and sweet dough mixes, in spice, chocolate, devil's food, yellow cake, and waffle mixes. Dried albumen ranks second in tonnage and is used in white and chocolate cake mixes and in special mixes such as cookie, macaroon, and angel cake. For home use the dried powder can be reconstituted with water, but, in products like cake with fat and in muffins, it can be sifted with the flour.

The Coordinated Dried Egg Research program, established in 1943, among government and industrial laboratories and colleges in Canada, England, and the United States had two goals: to produce (*a*) a dried egg with exceptional storage ability for the armed forces and (*b*) a dried egg of high functional ability. Good functional powders should form a sol rapidly with water (24). The literature on dehydrated eggs was already extensive. The intensified war effort resulted in many publications.

The chief disadvantage of egg powders is their instability. Loss of solubility is one instability defect. When this occurs the functional properties of the egg are decreased. The ability of the egg proteins to expand and hold occluded gas, such as air or steam, is important in the successful preparation of such products as popovers, cream puffs, sponge and angel cakes, meringues, and soufflés. When deteriorated egg powders are used in these products, the products are inferior to those made with fresh eggs and may even be unacceptable. Badly deteriorated egg powder will not coagulate or thicken in custards and batter and dough products.

Some factors affecting stability. Untreated egg white and whole egg are subject to the browning reaction. If the egg white is fermented before drying to remove the glucose from the white, the stability of the dried product is increased, but off flavors may develop (118, 119). The dried yolk, natural *p*H about 6.5, keeps better than the whole egg, *p*H about 8.5, probably because of the lower *p*H of the yolk (115). In solutions (88) the browning reaction is proportional to the temperature and the *p*H. The addition of 10–20% of sucrose or 10% lactose to egg before drying (14, 27) extends the storage life and aids in retaining the foaming power of the powder, but limits the use of the egg to products to which sugar is added.

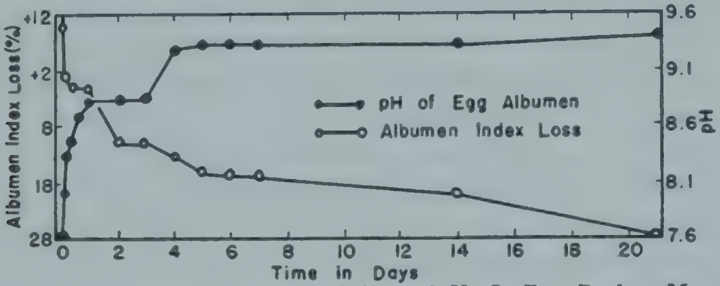
Extension of "shelf life" (defined as the time of storage during which the egg powder produced acceptable scrambled egg) of egg powder stored at 36.5°C was investigated by Boggs and Fevold (13). Shelf life was increased two- and fourfold, respectively, when the egg powder was packed in nitrogen or CO_2; two- to threefold when the egg magma was acidified to *p*H 5.5 before drying; five- to sixfold if the egg magma was acidified plus CO_2 or nitrogen packing. Acidified powders also retained good beating properties in contrast to the unacidified. Low-moisture powders had longer shelf life than high-moisture ones. A moisture content of 3% or less is usually considered a low moisture content. Acidified egg powders after drying have sufficient dry sodium hydrogen carbonate blended with them to bring the *p*H back to neutral.

The source of the off flavor (31) is in a yolk fraction. In obtaining this finding, the whole egg was fractionated into white and yolk, and in turn the yolk into lipovitellin, livetin, acetone-soluble lipids, and crude acetone-insoluble phospholipids. The phospholipid fraction of the yolk is the source of the off flavor. The phospholipid-free fractions of the yolk developed rancidity when stored alone, but not when stored in the presence of the phospholipids. Thus the phospholipids appear to act as antioxidants. It is suggested that fluorescence is not always a reliable criterion in determining palatability of egg powders.

*p*H

The egg white as ordinarily used is quite alkaline, in fact the most alkaline of any food with which the author is familiar.

Sharp (105) found the *p*H of the white to vary from 7.6 to 9.7. However, since the *p*H cannot be taken before the loss of some CO_2 occurs, Sharp thinks that a *p*H of 7.6 may be too high for freshly laid eggs. Wilhelm (128) obtained a *p*H of 7.62 for fresh eggs. The change in *p*H is dependent upon CO_2 loss and is also closely associated with loss of albumen index, shown in Fig. 50. Wilhelm found that the eggs from one-fourth of the hens had a *p*H above the average of the treatment whereas about one-eighth had a *p*H below the average in his studies. Since albumen quality is inherited, he thinks that it is logical that the *p*H of the egg albumen may also be an inherited characteristic. After reaching a value of *p*H 9.5, probably owing to breakdown of some of the proteins (105), the *p*H of the white decreases.



Courtesy L. A. Wilhelm and U. S. Egg Poultry Mag.

FIG. 50. The relationship between albumen index loss and increase in *p*H of egg albumen.

The *p*H of the egg yolk is much lower than that of the white. Sharp and Powell (109) state that it averages 6 or lower for fresh eggs, whereas Wilhelm (128) finds a value of 5.94. The yolk may reach a *p*H value around 6.8 after long storage (105), and it changes more gradually than the white.

Sharp and Powell (109) state that a *p*H of about 9.25 will be reached in 2 days at 37°C, in 5 days at 16°C, and in 10 days at 2°C. If eggs are kept cool, during the first few days more CO_2 is retained, which confers an added preserving effect.

Egg Proteins

The extensive use of eggs in cookery is made possible by their protein content. The protein coagulates during heating, thus bringing about thickening as in custards or the binding of pieces of food together as in croquettes. The proteins of the egg are good emulsifying agents. The protein forms elastic films when beaten, thus incorporating air, which is used as leavening in such products as angel cakes and soufflés. The elasticity of the egg protein is also important in products like popovers, in which the protein stretches with expansion of steam and later coagulates to aid in forming the framework of the product. Fevold (32) has reviewed the literature on egg proteins.

The proteins of the egg white. The proteins of egg white (101) are: ovalbumin, conalbumin, ovoglobulin, ovomucin, and ovomucoid. The first three are simple proteins; the last two are glycoproteins. The relative proportion of the total protein (101) of the egg white for each of the proteins in the order given is about 75, 3, 2, 7, and 13%. Fevold (32) states that albumin constitutes about 3/5 of the proteins of egg white. To these proteins should be added avidin. Major constituents (34), with the exception of the ovomucin, which is responsible for the structural characteristics of the thick white, are expected to be common to all portions of the egg white. Electrophoretic studies have shown that some of the egg proteins are composed of more than one component, ovalbumin has two, ovoglobulin three (35, 36, 74). Frampton and Romanoff (38) have reported ten electrophoretic components in the white of the hen's egg.

Ovalbumin is coagulable by heat, soluble in half-saturated ammonium sulfate, and precipitated by alcohol. It (32) contains a small amount of phosphorus, 0.10–0.13%. Electrophoretically albumin (35, 36, 74) consists of components A_1 and A_2, which migrate at different rates in an electric field. The proportion of A_1 and A_2 varies somewhat in different preparations, but is roughly about 4:1 (35). The isoelectric point (32) of ovalbumin has been reported as 4.7 and 4.8.

Conalbumin is heat coagulable (7). It (74) can be precipitated by acidification of the egg white to *p*H 4.0 or lower. It is more soluble than ovalbumin in ammonium sulfate. An outstanding characteristic of conalbumin is its ability to form a complex with iron. Schade and Caroline (102) found that in this complex the iron is no longer nutritionally available to certain microorganisms. Subsequently it was established (2) that the iron-binding component of the egg white is conalbumin. This complex is pink colored in the presence of oxygen. The isoelectric point (32) has been reported as *p*H 5.6 and 6.0.

Ovoglobulin is coagulable by heat. It is insoluble in half-saturated ammonium sulfate (32). Electrophoretically (35, 36, 74) it has been divided into three components, G_1, G_2, and G_3. G_1 is lysozyme, which has bacteriolytic properties for certain microorganisms. Globulins G_2 and G_3 (74) have isoelectric points of *p*H 6.0 and 5.6, respectively. G_2 is an euglobin, soluble in 0.25% NaCl, insoluble in water over a *p*H range of 5.5–7.5.

Ovomucin is the least soluble of the egg-white proteins. It can be precipitated by dilution with water (132) or by centrifuging (37). Young (132) obtained the largest amount of mucin with 1 volume of egg white and 2 volumes of water at *p*H 6.4 at 0°C. The standard analytical procedures for mucin are inadequate. This was shown by Forsythe and Bergquist (37). They found that the ovomucin was removed by the process. It has been considered that ovomucin is largely responsible for the structure of thick egg white. Hughes and Scott (59) reported 1.91 and 5.11% ovomucin in the thin and thick white, respectively; McNally (79) reported 0.66 and 5.7%. Forsythe and Bergquist were unable to find mucin fibers in unaltered thick white by microscopic observation, using a dark-field illumination. When the thick white was gently stirred, fibers were evident at a fairly low magnification.

Ovomucoid (39) has unusual stability. No denaturation is apparent after heating for 1 hour at 100°C. It has a high carbohydrate content. The mannose and glucosamine constituting approximately 27% of the protein (39) has been correlated with ovomucoid. The isoelectric point of ovomucoid has been reported as 3.9, 4.3, and 4.5 (32).

Avidin is similar to a typical globulin in that it is soluble in salt solutions and insoluble in water. It has the property of combining with biotin, making the biotin biologically unavailable (32). Avidin is inactivated by heat, but is fairly stable to *p*H changes. The method of combination of avidin and biotin (32) is obscure.

Biological activity. Fevold (32) states that, although the proteins of the egg white collectively have high nutritive value, individually, some of them appear to have been laid down for other purposes. They have specific biological activities which suggest protection against harmful bacterial invasion. Thus mucoid (71) inhibits trypsin; lysozyme lyses microorganisms; avidin binds biotin; mucin (32) inhibits hemagglutination; and conalbumin combines with iron, which may retard the growth of microorganisms requiring iron.

The proteins of the yolk. The egg yolk proteins (32) are largely phosphoproteins associated with smaller amounts of "water-soluble" proteins. The phosphoproteins compose about 30% of the egg-yolk solids. Alderton and Fevold and Fevold (1, 32) separated the phosphoproteins into two components. One component was called lipovitellin, the new one lipovitellenin. The vitellenin contains about 36–41% combined phospholipid (mostly lecithin). The vitellenin differs from vitellin in being unstable to acetone and in dispersing to a milky suspension in 10% NaCl whereas the vitellin is soluble. Vitellin contains 1%, vitellenin 0.29% phosphorus.

Livetin composes the water-soluble fraction of egg yolk. Electrophoretic studies (112) indicate it has three components. The livetin fraction of egg yolk (32) contains a majority of the enzymes of the egg.

Phosvitin. Mecham and Olcott (81) extracted this phosphoprotei from egg yolk. It contains about 6–7% of the total protein of egg yolk but 60–70% of the total phosphorus of the yolk. It is alkali labile.

None of the egg yolk proteins (32) have been shown to be isolated i pure form.

Coagulation of Egg Proteins

The terms denaturation, coagulation, and gelation as applied in egg cookery may be confusing. Denaturation has been defined in Chapter 1 as loss of certain specific properties of the native protein. Gelation, as used herein, refers to the formation of a gel; coagulation, to rendering the egg proteins insoluble. Heat is used for gelation and coagulation, so that to a certain extent the two terms are synonymous.

Salts, acids, surface reactions, mechanical agitation, radiation, and heat may have a part in coagulation of egg proteins. But, however the process of coagulation is brought about, the coagulation temperature, the time required for coagulation, and the factors that cause variation in coagulation temperature are of interest in egg cookery, because they determine the temperature to which certain dishes, such as custards and cooked salad dressings, may be heated.

Neurath et al. (90) state that denaturation can be averted by use of denaturants which exert a dispersive action, such as urea and guanidine chloride.

Coagulation temperature of egg white. In coagulating, the egg white changes from a clear, transparent mass to a white, opaque one. The temperature at which this change becomes visible varies with the rate of heating. The temperature is low if the rate of heating is very slow. The undiluted egg white coagulates around 60°C (the temperature is lower with very slow heating) and becomes so thick that it will not flow at 62°C or higher, although the jelly-like consistency is soft. The white becomes firmer as the temperature is elevated.

The coagulation process is endothermic. This can be observed in heating the custard mixture in Experiment 41A. As coagulation occurs the temperature (depending on the rate of heating) may remain stationary or drop. When the temperature starts to rise after a stationary period, it is an indication that the curdling point of the custard is near.

Coagulation temperature of the egg yolk. The egg yolk requires a higher temperature for coagulation than the egg white. It begins to thicken near 65°C but does not reach a stage at which it does not flow until about 70°C. Since the yolk does not change color during coagulation it is more difficult to determine when it is coagulated.

Temperature coefficient of coagulation. The rate of coagulation increases with increasing temperature, at high temperatures being so rapid that it seems nearly instantaneous. Chick and Martin (21) state that "heat coagulation is a reaction with a high temperature coefficient, the reaction velocity of which varies considerably with different proteins and according to the acidity and saline content of the solution." They found the temperature coefficient for a 1% crystalline egg albumin in water solution to be 1.9 for 1°C rise in temperature. This is equivalent (3) to coagulation taking place 600 times more rapidly when the temperature is raised 10°C.

The temperature coefficient is greater than 2 for the results of Lepeschkin (70) as tabulated.

°C	Seconds Required for Coagulation
57.04	22,600
58.01	9,520
59.03	1,535
60.03	595
61.02	230
62.01	97
63.01	40

As the temperature is elevated the firmness of a custard increases until at a definite temperature, depending on the rate of heating (being lower with a slower rate), an optimum consistency is obtained. Heating to a temperature higher than this brings about porosity and finally syneresis and curdling.

Woodruff and Meyer (131), with 0.2 *M* and 0.05 *M* NaCl and 0.2 *M* $MgCl_2$ distilled-water solutions substituted for the milk in custards, have found that the strength of the gel, when tested by a gel tester, progressively increased by increasing the temperature from 79° to 91°C by 4° intervals. As with milk custards the gels at the higher temperatures were porous and undesirable. The concentration of egg used was approximately 2 eggs per cup of liquid plus 23% of sugar.

Concentration of the protein. Dilution of the protein elevates the temperature for coagulation. This is illustrated by decreasing the amount of egg to a cup of milk in custard.

Salts: their concentration and valence. Lepeschkin (70) has shown that, if egg white is dialyzed so that the salt content is lowered, the albumin does not coagulate on heating. He has also shown that coagulation varies with the salt concentration, that some concentrations cause coagulation and others do not. However, if egg albumin which has been dialyzed until free from salts is heated in solution, and salts are then added in optimum concentration, coagulation occurs.

This can also be shown by substituting distilled water for milk in custard. This reduces the salt content of the custard mixture. This mixture will not gel when heated to 83–86°C. Many salts, such as lactates, chlorides, sulfates, and phosphates aid in bringing about gelation. Some salts produce firmer gels than others. The salt may be added before or after heating. However, if added after heating is completed, the stirring in adding the salt causes curdling.

$MgCl_2$ and NaSCN (131) produced stronger gels than milk; NaCl. Na_2SO_4, and $CaCl_2$ gave weaker ones. The difference in strength of the gels formed seems to be a specific function of the cation and anion of the salt used.

Concentration. The effect of varying concentrations of salts on gelation may be shown with $FeCl_3$. If just enough $FeCl_3$ is added to the distilled water in a glass container to give the water a slightly yellowish tinge when held over a white object, gelation is brought about in distilled-water custard. A large quantity of $FeCl_3$ causes curdling of the egg when added to the custard mixture, but upon heating brings about peptization of the egg.

Valence. Tofte and Morr (122) used varying amounts of solutions of NaCl, $CaCl_2$, and $FeCl_3$ with sufficient distilled water to substitute for the milk in the recipe given under Experiment 41. Although tests were not extensive, they did show the effect of valence, maximum gelation being brought about by 1.2, 0.3, and 0.09 grams of NaCl, $CaCl_2$, and $FeCl_3$, respectively.

Woodruff and Meyer obtained gels of approximately equal strength with 0.4 M NaCl, 0.1 M $MgCl_2$, and 0.05 M sodium citrate.

pH of the custard mix. The effect of adding acid or alkali depends upon the resulting *p*H in relation to the isoelectric point of the proteins. Adding an optimum quantity of lemon juice to a distilled-water custard produces a soft gel with heating. A larger or smaller amount of acid delays gelation. When salts were present (131) changing the reaction of a distilled-water custard from *p*H 3.5 to 9.0 did not, in general, produce significant change in the strength of the gel, except with sodium citrate and NaH_2PO_4, when the gel strength increased with decreasing acidity. The addition of 0–1.9 grams of cream of tartar to 100 grams of egg white (11) decreased the initial temperature of coagulation.

Chick and Martin (21) state that the acid hastens the second step of coagulation, and that the effect of acid in accelerating the coagulation rate of a neutral solution is at first relatively small, but becomes disproportionally greater with each successive addition. Loeb (72) found that isoelectric egg albumin in a 1% solution at *p*H 4.8 coagulated at a temperature not far from 60°C. When the *p*H was lowered below the isoelectric point to *p*H 4.39, coagulation occurred at 80°C but at *p*H 4.25 did not occur at 95°C.

If the solution is sufficiently alkaline (21), the second part of the denaturation-coagulation process does not occur. After heating, if the alkalinity is neutralized with acid, coagulation occurs.

Sugar. The addition of sugar to egg proteins elevates the temperature of gelation, coagulation, and curdling, thus retarding heat denaturation. It also retards surface denaturation of egg white. Its effect is proportional to the amount added. Bancroft and Rutzler (8) state that a "15 per cent egg white sol was not prevented from coagulating by the addition of 0.25 gram of dextrose to 10 cc of the sol. However, when the sol was saturated with respect to dextrose heating in boiling water caused no coagulation."

Barmore (11) varied the amount of sugar (0–90 grams) added to 100 grams of egg white and found that the temperature of coagulation was elevated from 69.5° for the sample containing no sugar to 85.5°C for that containing the most sugar.

Woodruff and Meyer (131) found that 10% of sucrose reduced the gel strength of egg-milk custards heated to 83°C approximately one half. Adding 30% of sugar nearly prevented gelation. Increasing the sugar also increased the translucency of the custard.

Coagulation by other means. Flosdorf and Chambers (33) found that audible sound, frequencies 1000–15,000, coagulated solutions of egg albumin and synthetic plasterin almost instantly at 30°C.

Jellinek (63) placed a raw egg between two condenser plates connected to a short-wave radio transmitter. After power of 1000 watts had been applied for 5 minutes, the egg yolk was coagulated and hard, as if it had been cooked, but the white was scarcely affected. The temperature of the yolk at the end of this period was 60°C (140°F); that of the white, 80°C (176°F).

Denaturation and digestibility. Cohn and White (22) found that cooked egg white digests more easily than raw egg white, the heating periods up to 30 minutes increasing the degree of hydrolysis of egg white by trypsin.

Cooked Salad Dressings

When other ingredients are kept constant (Experiment 42) with the rate of heating also constant, results similar to those shown in the table may be obtained.

		WATER	*p*H ABOUT	COATS SPOON °C
Vinegar	⅛ cup	⅞ cup	4.2	82 to 85
Vinegar	¼ cup	¾ cup	3.9	78 to 80
Vinegar	½ cup	½ cup	3.6	76 to 78
Lemon juice	⅛ cup	⅞ cup	3.6	82 to 85
Lemon juice	¼ cup	¾ cup	3.3	78 to 80
Lemon juice	½ cup	½ cup	2.8	76 to 78

The results emphasize some points discussed under coagulation of proteins. A larger quantity of acid produces a stiffer product and lowers the gelation temperature. Maximum thickness is determined by the rate of heating and the proportion of ingredients. If the salad dressing is removed at maximum thickness and stored in the refrigerator up to 6 months, no change in thickness of the dressing occurs. But, if the heating is continued after maximum thickness has occurred, the dressing becomes thinner; if heated long enough and evaporation is not too great or if evaporated liquid is replaced, the dressing may practically reach its uncooked consistency. It is one illustration in food preparation in which it appears that partial reversibility of heat coagulation has occurred. It s more likely acid dispersion of the protein hastened by the heating. Curdling is more likely to occur with vinegar than with lemon juice when the salad dressing is heated above the temperature for maximum thickness. This may be due to the difference in the two ions, citrate and acetate.

Salad dressing containing starch. It is evident, if maximum thickening from both egg and starch is obtained in a cooked salad dressing, that the starch and water must be heated to 95°C or boiling before the egg is added. Maximum thickening of some starches occurs at 91°C or boiling.

On the other hand, there is the possibility that part of the egg protein may not coagulate in the presence of starch, and hence not aid in thickening the salad dressing. Bancroft and Rutzler (8), quoting Berlinsson, state that "albumin is prevented from coagulating even in boiling water in the presence of starch." However, this appears contrary to observed results in food preparation.

Hollandaise Sauce

The egg yolk serves two functions in Hollandaise sauce: to thicken the sauce and to emulsify the fat. Note that Hollandaise sauce thickens at a lower temperature, 66–74°C, than cooked salad dressing or custards. If the temperature of the vegetable, fish, or meat on which the sauce is served is higher than 74°C curdling may be brought about. A curdled Hollandaise sauce may be reformed by beating as a small amount of warm water is added (122).

Eggs Cooked in the Shell

For eggs cooked in the shell, coagulation is in progressive stages from the exterior towards the interior. The layer of white next the shell may be completely coagulated before coagulation has started at the center of the yolk.

Tests in which a thermocouple was sealed in the egg showed that the temperature at the center of the yolk was a fraction of a degree lower than that of the cooking water even after boiling 4 hours. Romanoff and Romanoff (101) give results of Sieke who found that after 9 minutes of boiling the center of duck eggs varied from 67° to 74°C, after 10 minutes of boiling from 78° to 80°C.

Time required for cooking. The time required for cooking depends upon the initial temperature of the egg, the temperature of the water, the quantity of water in relation to size of the egg, and the rate of heating. To have the yolk cooked uniformly requires: about 1.5 hours at 70°C (although the yolk is waxy and its color is more characteristic of the uncooked yolk); 25–35 minutes at 85–90°C; and at least 12 minutes at 98–100°C.

Effect of temperature of coagulation on firmness. Temperature of coagulation cannot be considered apart from time of heating.

Barmore (11) mixed egg white thoroughly and placed it in cement briquette molds. These molds were placed in water of varying temperature and left 40 minutes. The firmness of the egg was determined by its tensile strength and the depth a steel ball and rod would penetrate. The white cooked at 77.5°C or below was too tender to handle. In general, the firmness of the white increased with elevation of cooking temperature.

If some fractions of the egg protein are heat coagulable at 70° and others at 85°C, then a long heating period at 70° would never completely coagulate the protein.

Poached Eggs

High-quality eggs are better for poaching than deteriorated ones. Shelly, Boggs, et al. (113) found a high degree of correlation between the albumen index of raw eggs and the quality of the poached and fried eggs. Eggs with a low albumen index failed to "blind or veil the yolk satisfactorily." In poaching eggs it is desirable to have the water near the boiling point when the egg is added. Thus the outer portion of the egg is coagulated in a short period of time. The cooking can then be completed at a lower temperature.

Since both the white and yolk tend to flatten on standing after being broken out of the shell, poached eggs of better appearance are usually obtained if the egg is broken just before it is added to the poaching water. The addition of NaCl to the poaching water (121), which probably already contains more or less electrolytes, aids coagulation but does not always improve the appearance. Some vinegar may also be added to the poaching water.

The Formation of Ferrous Sulfide in Cooked Eggs

When an egg has been cooked in hot water for 15 minutes or longer a dark greenish color may be formed on the surface of the egg yolk.

The yolk (101) contains more iron, 0.011%, than the white, 0.0009%. The sulfur content of the yolk is about 0.016%, that of the white 0.195%. The sulfur of the white is more labile and more easily split off by heat than that of the yolk. Marlow and King (80) say that the sulfur in egg whites and yolk is organically bound and that nearly all of it can be accounted for by the cystine and methionine sulfur.

Tinkler and Soar (123) have shown that the green color is due to the formation of FeS at the surface of the yolk. The white with prolonged heating at high temperatures evolves considerable quantities of H_2S. The hydrogen sulfide combines with the iron of the yolk to form FeS, which produces the green color. The amount of H_2S evolved depends on (*a*) the time of heating, (*b*) the temperature reached, and (*c*) the reaction of the egg. In a short cooking period little H_2S is evolved; likewise at a lower temperature a smaller amount is formed. Tinkler and Soar have also shown that the formation of FeS takes place very, very slowly until the yolk reaches a temperature of 70°C. It is very seldom formed in eggs cooked for 1 to 1¼ hours at 70°C, or in eggs cooked 30–35 minutes at

35°C. Thus both the temperature attained by all or a portion of the egg white as well as the time held at this temperature influence the amount of H$_2$S formed. In addition, as the reaction becomes more alkaline, the sulfur s split off more readily. Therefore, the extent of deterioration of the egg lso affects the amount of H$_2$S formed. This explains why some eggs have more FeS formed than other eggs when cooked at the same time and cooled n the same manner. Tinkler and Soar have reported that the uncooked yolk is acid in reaction but upon being heated above 70° becomes alkaline.

Effect of rapid cooling upon formation of ferrous sulfide in cooked eggs. H$_2$S is a gas. When the egg is placed in cold water mmediately after cooking the lowering of the temperature at the surface of the egg lowers the pressure there. One of the things learned in connection with the gas laws is that the pressure increases with increasing temperature. Since the white near the shell reaches a certain temperature more rapidly than the white near the yolk, more H$_2$S is split off near the shell. But, since the temperature near the yolk is lower, hence has less pressure than near the shell, the H$_2$S diffuses through the white towards the yolk. However, if the egg is placed immediately in cold water after cooking, the H$_2$S diffuses to the surface of the egg, owing to the reduced pressure, but if the egg is left in hot water, or to cool in the air, the gas does not diffuse so quickly to the surface and FeS is formed at the junction of the egg white and yolk. Tinkler and Soar have found that eggs cooked 15 minutes in boiling water and cooled slowly have some green color at the surface of the yolk; if cooled quickly, none or very little green color develops. Cooking in boiling water for 30 minutes gives a great deal of green color, no matter how the eggs are cooled, for FeS has already formed. The sulfur compounds of the yolk are so stable that the egg can be cooked as long as 7 hours without the interior of the yolk becoming green.

Sulfides and flavor. Large quantities of sulfides give a characteristic odor and flavor to the egg.

Custards

In a custard mixture most of the heat-coagulable protein is furnished by the egg; about 0.75% of the milk protein is heat coagulable. As this mixture is heated, gelation occurs to form custard. If the temperature is held a long time at the gelation point or carried beyond this point, the custard shows syneresis. This is called the curdling point.

Forewarming of the milk for custards may tend to prevent curdling of the milk, but its greatest advantage is probably in shortening the cooking period.

Custards may be cooked in two ways, with and without stirring. They are usually designated as baked and soft custard, respectively. The baked custard is firmer than the soft or stirred custard and appears to be in one piece or clot.

Gelation temperature of custards. The temperature at which gelation starts varies with varying proportion of ingredients, the rate of cooking, the quality of the eggs, and the *p*H of the mixture. Because of the variables stated, no definite temperature can be given to which a custard should be cooked. If a thick layer of custard clings to the spoon (known as "coating a spoon"), a serving consistency has been reached. Since the denaturation-gelation reaction is endothermic, if the rate of heating is not too rapid, the temperature will remain constant during this thickening. The end point of cooking can be taken when this period is reached, or, if the period is not too long, cooking can be stopped when the temperature starts to rise again. If cooking is stopped at this latter stage, rapid cooling may be advantageous. With ordinary rates of cooking, a serving consistency is usually obtained between 82° and 84°C.

When substitutions are made on the basis of 2 yolks or 2 whites for 1 whole egg, if other conditions are standardized, the custard made with egg white thickens at a lower temperature than that made with the whole egg. In turn the whole egg thickens at a lower temperature than the egg yolk. However, on the basis of gram for gram, the yolk has more thickening ability than the white.

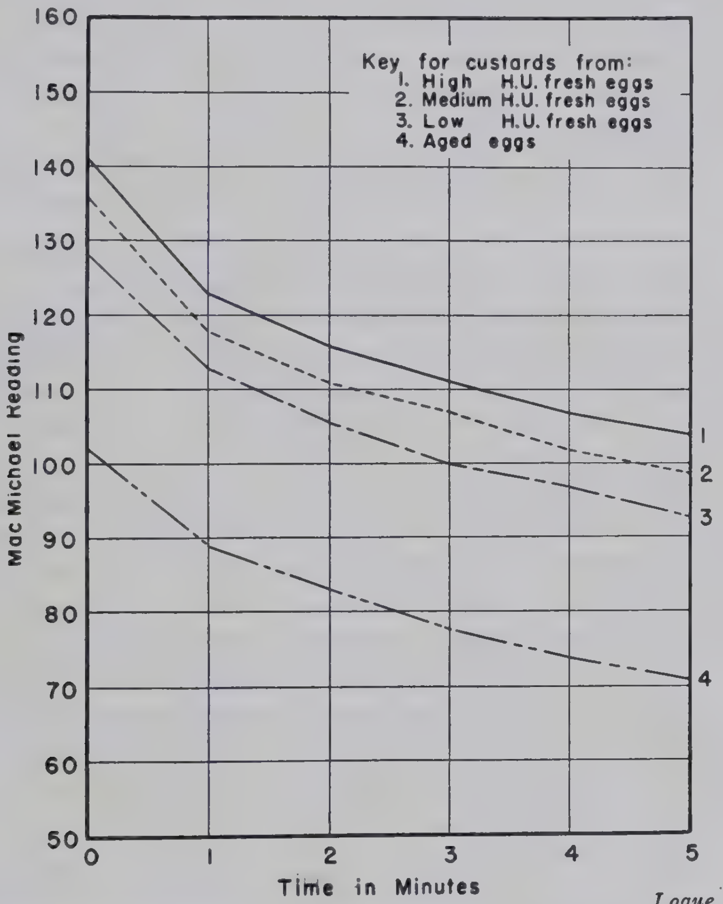
Sugar and egg. Increasing the proportion of sugar raises the gelation temperature and gives a less stiff custard. Increasing the concentration of egg lowers the gelation temperature and gives a stiffer custard.

Rate of cooking. It is possible to heat a cup of custard mixture in a double boiler from room temperature to the curdling point in less than 3 minutes. With this rapid rate of heating the custard generally curdles at about 89°, often after the temperature has remained stationary at 89° for a time. It may reach 91° or 92° and then drop back to about 89°, the curdling occurring before a serving consistency is attained.

When the custard is cooked slowly, and particularly if the heating is very slow after 75°C is reached, gelation is quite perceptible at 78°, and the custard has a serving consistency from 80° to 84°, that cooked more slowly being thicker at the lower temperature. A slower rate of cooking is preferable to a rapid one, for the thickening is evident for some time before the curdling point is reached. With the rapid cooking, the custard requires very close watching and rapid work to remove it from the heat before the curdling temperature is reached. Curdling may occur at 82–84° if the temperature is raised very slowly, but in ordinary cooking it is more likely to occur between 85° and 87°C.

Egg quality. Logue (73) used three series of fresh eggs of different interior quality, as measured by Haugh units (the eggs were 1 day old when broken to determine the quality and 2 days old when used in custards) and one series of eggs as nearly uniform as possible, aging at room temperature throughout the study. The age of the last group of eggs when ised varied from 4 to 25 days. All four series were used in baked (cooked o 82°C) and stirred custards (cooked to 83°C).

The mean viscosity curves for the stirred custards are shown in Fig. 51. The decrease in viscosity of the custard with increase in time is characterstic of gels (egg, gelatin, starch, fruit) which are stirred. The torsion on



Logue

FIG. 51. Mean viscosity curves of soft custards made from fresh eggs of varying Haugh units and from aged eggs.

the viscosimeter pendulum is similar to stirring the custard. The MacMichael viscosimeter could not be used with the baked custards because the gel broke with separation of a liquid phase. In all other tests the rank for baked and soft custards were in the same relative order. An aluminum cone of 90-degree angle was used with a penetrometer for depth of penetration tests. A smaller angle would have given deeper penetration. The results of all tests for stirred custards are shown in Table 23.

pH of the custard mix and cooked custard. The relations between the *p*H of the egg white, custard mix, and cooked custard are shown in Table

TABLE 23

Mean Haugh Units, Rank for Stiffness Scores, MacMichael Readings, and Depth of Penetration for Soft Custards (*Logue*)

Egg quality	Haugh units	Rank for stiffness	MacMichael readings	Depth of penetration
High H.U. fresh eggs	88.9	3.2	104.0	227.3
Medium H.U. fresh eggs	81.3	3.0	98.8	232.6
Low H.U. fresh eggs	72.5	2.1	92.6	232.8
Aged eggs	57.5	1.8	71.0	233.1

24. Note that the cooked custards are usually more alkaline than the custard mix; the fresh eggs less alkaline than the aged ones.

It could be argued from the results in Table 24 that the pH as well as egg quality affected the results. Egg quality is closely correlated with the pH of the egg.

TABLE 24

Mean pH of Egg White, Custard Mix, and Cooked Custard (*Logue*)

Egg quality	Baked custard			Soft custard		
	Egg white	Custard mix	Cooked custard	Egg white	Custard mix	Cooked custard
High H.U. fresh eggs	8.37	6.50	6.54	8.32	6.50	6.60
Medium H.U. fresh eggs	8.38	6.51	6.55	8.38	6.49	6.59
Low H.U. fresh eggs	8.41	6.52	6.57	8.41	6.50	6.60
Aged eggs	8.98	6.56	6.58	8.88	6.57	6.62

Agitation during cooking. Since stirring lessens the viscosity of a gel, the stirred custards are not as stiff as a baked custard. However, the kind of agitation seems to make some difference in the results. Sweet (122) divided custard mixtures, stirring one portion with a spoon, the other with an electrically operated stirrer. The custards stirred with the electrically operated blade were stiffer, smoother, and more palatable. When these tests were repeated, using the same stirrer but a different blade, results were duplicated except that those stirred with the electrically operated stirrer were not as stiff as the custard made with the first blade.

Frozen and dried egg. Frozen egg may produce custards comparable to those made with fresh eggs. If considerable gelation of the frozen egg has occurred, it can be combined more readily if it is blended with the sugar before the milk is added. With considerable gelation of the frozen egg, penetration and palatability tests indicate that the custard is less stiff than when made from fresh eggs.

The acceptability of custards made with dried egg powder depends chiefly on the solubility of the powder (26, 64). McBride (75) found that dried whole egg of good quality produced baked custards comparable to those made with fresh or frozen eggs. The dried egg was reconstituted in water at 25° and 70° and in milk at 65–70°C. The resulting custards were similar except that the powder reconstituted in milk was stiffer. As the quality of the dried egg deteriorated, as indicated by progressive loss of solubility, the custard became thinner. With a very insoluble sample a rubbery egg layer formed across the top which could be lifted off practically intact; the custard beneath this layer was very thin and a light color.

Pie Fillings

Custard. In cooking custard pie one of the major difficulties is to prevent soaking of the crust. Increasing the proportion of egg helps, as the custard then coagulates at a lower temperature. Thus 1.5 eggs to a cup of milk is better than 1. Prewarming the milk before adding it to the other ingredients shortens the time before gelation takes place.

One way to prevent soaking of the crust is to cook the pastry and the filling separately. Bake the pastry on the bottom side of a pie pan with sloping sides. Bake the custard in a pie pan of the same size as the one used for the crust, setting the pan in hot water and using as low an oven temperature as desired. After baking the custard, cool it until the pan feels warm but not hot to the hand. At this temperature it has set sufficiently to hold together, yet will not break so easily as when cold. Run a knife or spatula around the edge of the custard and, tilting it at about a 45-degree angle, shake and slide it out of the pan into the crust.

Butterscotch and other fillings. One question often asked is why butterscotch fillings for pies which are of a consistency for serving sometimes become thin and runny after standing for a short time. This, of course, is different from the instances in which thickening does not occur. Various factors may bring about this result, but the effect of the sugar in elevating the temperature at which egg coagulates is one explanation. The proportion of sugar in butterscotch fillings in different recipes varies from about 15 to 25%, or 15–25 grams per 100 grams of filling. A usual procedure is to cook the sugar, cornstarch or flour, and scalded milk until thick. This mixture is often added to the beaten yolks by stirring the hot mixture into the yolks. Sometimes it is considered that the hot milk mixture will coagulate or cook the egg yolk sufficiently. However, if the temperature drops below 80°C during this procedure and the mixture is not reheated the egg yolks will not be cooked sufficiently. The filling appears thick at the time, but on standing it becomes runny. If sugar is added to uncooked egg yolks, mixed, and left to stand for a few minutes the mixture appears thinner and more runny. If the yolks are not cooked sufficiently they act in much the same way, the sugar dissolving in the uncooked yolk and the filling becoming runny. This has never been observed by the author if the mixture is heated to a sufficiently high temperature after the egg yolks are added. Another possible factor in the thinning of the filling is the tannin of the brown sugar, which has a dehydrating effect on many sols. But to date it has not been possible to obtain thinning in butterscotch filling by adding slightly more tannin than might be found in the sugar.

The thinning of the filling also occurs with chocolate, banana, coconut cream, and lemon fillings. In lemon pie filling too little starch may be used, but this thinning is usually evident before the egg is added.

Egg White Foams

The essentials for a stable foam were discussed in Chapter 1. They are a low surface tension, a low vapor pressure, and a tendency for the substance in the surface to solidify, hence giving rigidity and permanence. Egg white fulfils these requirements. In egg white foams some of the rigidity is caused by coagulation of part of the protein at the air-egg-white interface.

Changes in egg white with beating. As the egg white is beaten the following changes gradually occur: (*a*) the enclosed air bubbles become progressively smaller; (*b*) the color changes from a pale greenish yellow (flavin pigment) translucency to an opaque white; (*c*) the stiffness and volume increase; (*d*) as the area of the film increases the elasticity is decreased and the foam becomes more rigid and brittle; and (*e*) the surface changes from a moist shiny appearance to a dull or dry one, and, with some egg beaters, small flocs appear. This last is the stage called dry by cookbooks.

Methods of testing stiffness. There are several ways in which the stiffness may be tested. For household use the tests are (*a*) appearance, (*b*) the height of peaks and the extent to which the point bends over when the egg beater or some utensil is lifted out of the beaten white, and (*c*) the rate of flow when the bowl or plate in which the white is beaten is partly inverted. A skillful operator working constantly with egg white soon learns to judge the degree of stiffness by these common household methods, and the degree of proficiency that can be attained is surprising. But for experimental purposes the same degree of stiffness probably could not be duplicated in another laboratory from the description. In the home the height of the peaks, and particularly the extent the point falls over, are the best criteria for judging stiffness. The rate of flow is not quite so good unless the same quantity of egg white is always used, for a large quantity must be beaten stiffer to flow at the same rate as a smaller quantity.

For laboratory purposes (*a*) the specific gravity can be used to determine the relative amount of air occluded in different foams, (*b*) the meringue test may be used to predict the angel cake volume from the foam, and (*c*) the stability of the foam may be determined by the amount of drainage from the foam in a given time. The meringue test (114) was devised to correlate the beating rate of the meringue with the volume of the angel cake. The meringue contained all the ingredients of the angel cake except the flour and about a fourth of the sugar. Beating the meringue was carried out under standardized conditions. Numerous tests indicated that egg white that forms a foam rapidly always produces an angel cake of high volume; however, egg white that beats slowly does not always give a cake of poor volume. The specific volume of the meringue is calculated by dividing the foam volume (in milliliters) by the foam weight (in grams). Rate of beating is determined by dividing the specific volume by the total time of beating. Thus, rate of beating is expressed in increase in specific volume of foam per second of beating (milliliters per gram per second).

The stability of the foam has been tested in two ways. In one test (56) semispheres of the foam were put on pieces of paper to dry. The volume after drying was noted. To photograph, the semispheres were cut in halves. A simpler method is to put a given weight of foam in a funnel of known capacity and bore. The funnel is covered to prevent evaporation. If the funnel is placed in a graduated cylinder, the drainage may be read in milliliters or the weight taken at the end of a definite time, usually 30, 40, or 60 minutes. With slight beating the egg white is runny and not stable so that both the unbeaten egg white and foam drain from the funnel. After a certain stage of beating maximum stability is reached and little drainage occurs. With still longer beating the stability is decreased (11, 47) and drainage increases.

Salt and the whipping of egg white. When 1 gram of salt (47) was used with 40 grams of egg white, the resulting foam was similar to an egg white foam without salt, except in stability. The addition of salt decreased the stability of the foam.

The addition of sugar to egg white foam. Hanning (47) describes egg white foams as follows: The egg white foams without sugar formed very quickly (a KitchenAid, second speed), but were not smooth and plastic. Coagulated flocs formed after 8–10 minutes of beating. The peaks following the egg beater as it was removed from the foam were not tall, but abrupt and short. The foam tended to "set" and stiffen after beating was stopped; was friable in texture; and began to drain quickly. In contrast, the egg white foams with added sugar were pliable. The foams followed the egg beater into long, slender peaks; flocs did not form with less than 24 minutes of beating; the foam did not fly off the beater with less than 25–30 minutes of beating; and, the foams were more stable. There is a lag in expansion and stiffness of the foam with added sugar. Thus a longer time is required to beat the foams, but the presence of sugar also makes it more difficult to overbeat the foam. Because sugar increases the stability of the egg white foam, it is a good practice to add sugar to the egg white after 5 to 10 seconds of beating when whites fo angel cake and meringues are whipped at high speed on a machine.

Acids and stability of egg white foams. The addition of certai acids or acid salts increases the stability of an egg white foam. "The firs portion of the beating period is superior to the latter for adding acid t egg white" (9).

Cream of tartar, acetic acid, and citric acid (9, 11) produce egg foam of practically the same stability at *p*H 8. However, at *p*H 6, as th acidity is increased by adding a greater concentration of these acid substances, the cream of tartar foam is the most stable, the acetic acid one th least. There is a limit to the amount of acid that can be added, an amoun beyond the optimum being detrimental to foam formation. The additio of acid delays the formation of the foam; *i.e.,* if beaten with the same eg beater for a definite time the foams containing acid are not so stiff as thos from which it is omitted. This is particularly true for both acetic an citric acids (see omelets).

Egg white is partially coagulated during beating. In whippin the egg white is finely divided, and stretched in films around the air bubbles But the beating has caused other changes in the egg white. In speaking o the methods by which coagulation may be brought about, Ostwald states "When egg white is beaten to a foam, a part is regularly coagulated in th walls enclosing the air bubbles. A decrease in degree of dispersion to th point of inducing coagulation can also be brought about through centrifuging, etc. These belong to the mechanical methods of producing coagulation."

By the ferricyanide method (47) it was determined that a larger number of active sulfhydryl groups were present in egg white foam after beating 3 minutes than in the initial egg white. Sugar retarded the coagulation of the protein, but whether its effect was exerted during denaturatio or subsequent coagulation was not determined.

Effect of temperature upon whipping of eggs. Surface tension i lowered with increased temperature. This probably explains, in part, wh eggs taken from the refrigerator and beaten while still cold do not whip u as quickly as when beaten at room temperature.

The Bakery Research Department of Procter & Gamble Company (98 has reported that, regardless of the length of time of beating, a given suga and egg mixture, when whipped at 15.5°C (60°F), will never become a light as a mixture of the same proportions beaten at the same speed an at a temperature of 43.3°C (110°F).

St. John and Flor (121) and Henry and Barbour (56) also obtaine greater volume at room temperature than at refrigerator temperature.

Season and age of eggs and whipping. The whipping quality o eggs varies with the season in which the eggs are produced. Nemetz (89 has reported experiments in which whole eggs that had been broken an frozen in April, July, and September were used in sponge cake and crean puffs. With all mixing and baking conditions standardized, the April eggs gave a 15% increase and the September ones a 10% increase in volume over the July eggs in sponge cake. Similar results were obtained in cream puffs.

Thick and thin white. Hunt and St. John (60) found that the thin portions of the egg white beat to a larger foam than the thick part. Bailey (4) obtained a larger volume from the thick portion when whipped with a Hobart-type mixer, but with an electric Dover-type the thin foam gave a larger volume. Thus the type of egg beater is a factor in the results obtained. It has also been established that the largest foam does not always produce the greatest volume in the cake. Henry and Barbour found that the thin white produced a larger volume in a shorter time than the thick white, but the thin lost volume with continued beating.

Physical treatment of egg white. Studies at the Western Regional Research laboratory (77) indicate that shear, not pressure, harms egg white. The beating properties of egg white were not damaged by pressure of 5000 psi but were damaged by homogenization at equivalent or less pressure. Homogenizing the white more than doubled the beating time, reduced the viscosity to less than half, and produced changes in the ovomucin fraction. Cake made from freshly homogenized egg white had appreciably reduced volume. Some of the homogenized material was stored 3–7 days at 2°C. During this period a reversion occurred in the material, so that cakes made from the stored white progressively increased in volume till they equaled those of the controls. Forsythe and Bergquist (37) reproduced these results with homogenized egg white, except for the regaining of the cake volume after storage of the homogenized material.

Blending egg white with a Waring Blendor (37) decreased the initial ovomucin fiber length rapidly. This was followed by a slow drop, the fibers reaching a constant length of about 200 microns. Accompanying this decrease in fiber length was a faster beating rate and a larger cake volume. The effect of high-speed centrifuging depended on whether shear of the egg white occurred in the process. Although the removal of mucin did not seriously affect the beating rate of the egg white, shear occurred when a continuous bowl was used. This degraded the albumen.

Egg beaters and their operation. Egg whips and hand-operated rotary beaters are made with wires and blades of varying thickness and design. If a collection of ten to twenty different kinds of beaters is made, a look at them is sufficient to understand that variation in foam volume, size of air bubbles, stability, specific gravity, the time required for beating, and the absence or presence of flocs may occur when different beaters are used. The fine-wired whips usually give better angel cake volume.

When using an electric-operated beater at high speed with several hundred revolutions per minute a few seconds' over-beating decreases foam stability. Adding sugar steadily as soon as the beating is started stabilizes the foam and lessens the danger of overbeating. However, for hand-operated beaters, it is better to beat the eggs until slightly foamy, add the salt and cream of tartar (if these are added), continue beating a short time, then beat the sugar into the foam gradually. If the sugar is added too soon the beating time is increased unnecessarily.

Whipping the egg whites to the same specific gravity cannot be taken as a standardizing procedure. For example, with a very fine-wired hand whip better products are obtained if the egg foam without sugar has a specific gravity between 0.09 and 0.10; with another beater a specific gravity of 0.15 to 0.17 produces better products.

The gear ratio for hand-operated rotary beaters is about 1:5; *i.e.,* 1 turn of the handle gives about 5 revolutions of the blades. If the handle is turned 120 rpm, the blades would turn about 600 rpm. The speed of electric mixers, depending on the particular mixer, the speed, and for some mixers the load or stiffness of material used, may range from 300 to 2400 rpm.

Whips or rotary beaters. One question often asked is whether better angel food is obtained with a whip or rotary beater. A great deal depends on whether the beater is a good type of its class or a poor one. Both can produce good products. In the majority of instances the students obtain larger volume with a fine-wired whip than with a good rotary beater.

Combination of egg albumen with metals. The foods department formerly had some copper-plated rotary egg beaters. After the plating wore off a pink color often developed in egg white when these beaters were used. The pink color has so far always developed in making angel cake in Experiments 46D2 and D4. The cream of tartar is omitted in D2 and added with the flour in D4. The color develops while the sugar is being folded in the egg white with a spatula. The pink color forms when some constituent of the egg white combines with the iron or copper. The color fades from the cake during baking. Some factor other than the presence of the metal is necessary to bring about the color change, such as *p*H and the assembly line method of making the cakes, for the color seldom develops when spatulas are used with egg white in other instances.

Meringues

Meringues vary in the quantity of sugar added and in their use. Only soft and hard ones will be considered here.

Soft meringues. One use for soft meringues is as a topping for pies. A meringue that leaks renders the top of the pastry filling undesirably moist and slippery and increases the difficulty in cutting. The factors in obtaining a desirable meringue are: the extent of beating the egg white, the time of adding the sugar, the method of adding the sugar, the baking temperature and time, and the optimum proportion of sugar to the egg white. Other factors affecting the result are whether water is added to the egg white (91), whether the meringue is placed on a hot or cold pie filling, and possibly the quality of the egg white. Short experimental studies (122) indicate that more stable meringues are obtained if the sugar is beaten into the egg during foam formation. The sugar can be added gradually after the egg white is foamy or before beating is started. The last procedure increases the beating time. Greater stabilization seems to be attained when the opportunity for solution of the sugar is greater, *i.e.,* in beating instead of folding. Overbeating the egg white before adding the sugar increases the tendency to leak.

The amount of sugar for a desirable meringue varies with the fineness of the sugar. In general, desirable sweetness and texture are obtained with the following: 2 tablespoons (25 g) of the fine or berry sugar (the common type for home use) per 1 egg white (about 30 g): as much as 3 tablespoons of the ultra-fine; but, less than 2 tablespoons of the coarse granulated sugar.

Hester and Personius (57) concluded that a desirable degree of coagulation of the egg in the meringue is an important factor in preventing leakage and beading in a meringue. Leakage was greatest in the experimental study when the meringue was placed on a cold instead of a hot filling prior to baking. The kind of filling also made a difference in the amount of leakage. The egg quality and the addition or omission of cream of tartar had little effect on the meringue. A wide range of baking temperatures was found adequate for coagulation if the baking time was adjusted accordingly.

Several short experimental studies (122) have indicated that the time for baking varies with the thickness of the meringue as well as temperature of filling. Desirable products were obtained with the following times and temperatures: 6 minutes at 220°C; 8 at 205°C; 12–18 at 175°C; and 18–25 minutes at 160°C. With temperatures below 160°C the baking time is long and the meringue often shrinks unduly after being taken from the oven.

Hard meringues. Hard meringues contain a larger proportion of sugar than soft ones. Because of the high sugar content they have a fairly smooth, somewhat crystalline, crisp crust. They are usually puffy in appearance and are used for accompaniment to, as a foundation for, or as a dessert.

The optimum amount of sugar appears to be 4–5 tablespoons per egg white, the smaller quantity probably being preferable. Since acid increases the tenderness of egg white, its addition is desirable. About 1–2 cc of vinegar per egg white may be used; however, since cream of tartar produces a more stable foam its use appears to be preferable. Cream of tartar meringues have scored higher in class work. About 1.5% of cream of tartar (about 0.45–0.5 gram per egg white or 30 grams of egg white) is satisfactory.

The sugar is added in the same manner as for soft meringues, but because of the larger quantity added, better results are usually obtained with hand beaters if it is added gradually.

With optimum proportions and kinds of ingredients, obtaining a crisp, very tender meringue depends upon the baking. Meringues should really be dried in the oven instead of baked. The oven is operated at as low a temperature as possible. For the latter part of the baking the meringues may be left in the oven after the heat has been turned off. The best meringues the author has ever eaten were baked by putting them in a fairly well-insulated institutional preheated oven at Purdue University, with heat turned off, and leaving them overnight.

Omelets

There are several types of omelets. They are designated in various ways as plain, French, and foamy omelets. Some have a white sauce or tapioca basis. In others, bread crumbs are used to absorb a part of the moisture. The type of omelet that has the egg yolk folded into the beaten white is sometimes called a foamy omelet. This is the type that requires the most skill in making and is the one mentioned here.

Mixing foamy omelets. The yolk is beaten until foamy and then folded into the stiffly beaten egg white. Sometimes during baking the liquid portion collects in the bottom of the cooking pan and coagulates there while cooking, forming a thick compact layer. This is due to insufficient beating of the whites, or insufficient mixing of the yolk with the white, so that the yolk is not sufficiently blended through the white to be held up by the framework or physical structure of the whipped white, or it may be due to standing too long after mixing before cooking is started. The pan into which the omelet is poured should be hot enough to start coagulation of the egg, but not hot enough to form a hard crust. However, overmixing and rough handling cause loss of a portion of the air incorporated into the egg white. Overbeating of the egg white before the yolk is added results in loss of extensibility, and the volume of the omelet does not increase as much as it should during baking. It is also drier and sometimes powdery.

Formation of ferrous sulfide in omelets. The green color that develops on the underside of the omelet is caused by the formation of FeS when some of the egg has separated and drained to the bottom of the pan. It may be prevented by sufficient beating of the egg white, by thoroughly blending the yolk and white, or by starting cooking promptly. The color may develop in omelets cooked on top of the stove, or in those cooked in Pyrex, but it occurs more often in those baked in the oven, for this type of cooking requires a longer time.

Kind of liquid in omelets. The liquid added to foamy omelets may be water, water plus cream of tartar, vegetable juice, tomato juice, fruit juice, vinegar and water, or lemon and water. If a tablespoon of milk is added to an egg white it will not form a foam. If added to the beaten white the volume is quickly reduced and the foam is destroyed. Dizmang and Sunderlin (28) investigated the effect of milk on the whipping quality of egg white. Their results, shown in Table 25, incidate that the fat of the

TABLE 25

THE EFFECT OF MILK ON WHIPPING QUALITY OF EGG WHITES
(*Dizmang and Sunderlin*)

Substance added to egg white	Largest number of drops added to one egg white, permitting formation of foam stiff enough to stay in an inverted bowl
Cream (20% fat)	1–2
Whole milk	2–3
Sterilized whole milk	8
Reconstituted powdered whole milk	50–70
Cream (20% fat) homogenized, 3000 lb	70
Evaporated milk	50–350
Separated milk	400–446
Whole milk, homogenized, 2500 lb	400–450
Whole milk homogenized at 3000 lb	1000
Reconstituted powdered separated milk	1600

milk is responsible for breaking the foam. But the size of the fat globules is also important, smaller particles having less effect.

The addition of 15 ml of a liquid to an egg white dilutes the protein and thus increases the tenderness of the omelet. But the acid ingredients give a much more tender product than water. The acid ingredients may produce a larger volume as well as a more tender omelet, but they also increase the time for beating the egg white considerably. The average *p*H of the omelet mix, to which 5 ml of lemon juice plus 10 ml of water is added to an egg, is around 4.6 to 4.9, which is near the isoelectric point of some of the albumen proteins. If the foaming properties of an egg white are also greatest at the isoelectric point of its proteins, this may explain obtaining the greater volume.

Temperature for cooking omelets. Omelets are usually cooked above heat, but baking them in the oven is an easy way to secure uniform temperatures for class work. Roost (122) found that 28 minutes at 165°C gave the most palatable or highest-scoring omelet.

Angel Cake

Review of literature on angel cake. Excellent work has been reported from different laboratories on angel and sponge cake.

Season of year. When cakes were baked each week throughout the year (16) from eggs of the same age, produced by the same flock on controlled feed, the quality of the cakes varied at different seasons. The quality was high in February and March, low in November and again in January. It was thought that, if the amount of beating had been standardized according to some factor other than time of beating, excellent cakes might have been obtained during the low months as well as the high.

Quality of egg. Hedstrom (54) found that the percentage of thin white increased, as did the *p*H, with increased age of the eggs. There was a progressive decline in cake volume with eggs from 12 to 52 days of age. Barmore (10) found that white of older eggs beat to a lower specific gravity than foams from fresh eggs, and the foam was also less stable. Harns et al. (49) found that, the higher the quality of the broken out egg, the more satisfactory is the resultant angel cake.

Temperature of the egg white for beating. Glabau (43) varied the initial temperature of the egg white at the start of beating by 2.8°C (5°F) intervals from 1.7° to 26.7°C (from 35° to 80°F). When all the egg-sugar meringues were beaten to a specific gravity of 0.176, cakes baked from eggs at 10°C (50°F) and 21°C (70°F) had the largest volume and most outstanding cellular structure. Too little or too much beating of the egg white produced cakes of smaller volume. Hunt and St. John (60) also obtained better cake volume at 21°C than from whites beaten at 5°C. Miller and Vail (85) obtained the best cakes when the egg whites were beaten at 21°C.

Thick or thin white. The results reported in the literature, when egg white is separated into the thick and thin portions, are contradictory. Stanley (116) states that the thin white beats to a larger volume than the thick white, but a cake of larger volume was obtained with the thick portion of the white. Opposite results were obtained by Hunt and St. John (60) and Miller and Vail (85). Several factors, such as the age of the egg when separated and the recipe used, may account for the discrepancy.

Cold and preheated ovens. Peet and Lowe (94) mixed 2 angel cakes at a time, divided the batter and started baking 1 cake in a cold, the other in a preheated oven. Cakes were baked in 6 ranges, 3 electric, 2 gas, and 1 kerosene. The batter of the cake baked in the preheated oven stood about an hour while the cake started in the cold oven was baking. In spite of this discrimination the cakes started in the preheated ovens were ranked superior to those started in cold ovens for texture, eating quality, tenderness (both scores and tensile strength determinations), moistness, and they also had larger volume, the results being significant at the 1% level.

Temperature of baking. Burke and Niles (16) consistently obtained better cake volume with less moisture loss during baking for 45 minutes at 178°C (350°F) than for 1 hour at 163°C (325°F). Cakes (11) baked at 178°C for 30 minutes had larger volumes and were more moist and tender, probably because of larger volume than cakes baked at 163°, 152°, or 138°C. The maximum temperature inside the cake does not vary appreciably, regardless of the oven temperature (11).

The time of baking must be adjusted carefully to the temperature of baking, the size of the cake, and the type of pan used. See discussion under baking angel cake, p. 363.

Type of range. The judges did not differentiate among cakes (94) baked in different ranges (electric, gas, and kerosene) for total scores, texture, and eating quality. In contrast, however, cakes baked in some ranges had better volumes and were tenderer than those baked in other ranges, the results being significant at the 5% level.

Altitude. Barmore (11) found that with increase in altitude the amount of expansion during baking increases; the cake becomes more tender; the final cake volume changes and is related to tenderness; the amount and rate of evaporation increase; the maximum internal cake temperature decreases; the volume of the vapor escaping increases; and the color of the crust becomes lighter.

Moisture lost during baking. Barmore (11) found that no moisture was lost by evaporation by any portion of the cake farther from the outer edge than 1 cm. "Cake baked at the low temperature appeared to contain less moisture, because the center of the cake felt and tasted much drier than that baked at a higher temperature for a shorter time. The data show that one was just as moist in the center as the other. The difference in feel was apparently occasioned by the difference in the condition or location of the moisture. Perhaps in the low-temperature cake the moisture had been more completely removed from the sugar solution and absorbed by the starch or protein, because of the greater length of time the cake was maintained at a high temperature." Another explanation of why the cake baked the longer time appeared more dry than the cake baked the shorter time was that more water was bound in the former instance.

Various factors. Barmore (11) determined "the influence of various factors, including altitude, in the production of angel cake." He concludes that the whites of fresh eggs should be beaten with 1 to 2% of cream of tartar to a specific gravity of not less than 0.15 and not more than 0.17. At *p*H 8 the stability of the egg white foam was practically the same for acetic and citric acids and cream of tartar. But at *p*H 6 the cream of tartar produced the most stable foam. Part or all of the sugar should be added before the addition of any of the flour, for the addition of the sugar strengthened the egg white foam; the volume of the batter decreased considerably more when the flour was added with the sugar than when it was added by itself, after the sugar had been beaten into the egg foam.

Carlin and Ayres (19) found that egg white treated with an enzyme preparation (deoxygenase) to remove the glucose before drying produced angel cake comparing with the controls in volume and flavor.

Carlin and Foth (18) found that thermostabilization of eggs in oil at recommended times and temperatures resulted in a reduction in the foaming ability of the egg white and a decrease of 10–20% in the angel cake volume.

Frozen whites. Schrenk (104) used three brands of frozen egg whites n home and institution mixers. The specific gravity of the meringue on the institution Hobart, 0.21–0.23, was higher than on the KitchenAid, 0.18–0.22. Several factors probably contributed to this result—the size of the mix and the number and size of wires of the whips (Hobart, 36 wires, $\frac{1}{10}$ inch in diameter; KitchenAid, 22 wires, $\frac{1}{12}$ inch in diameter). The cakes mixed in quantity were not as desirable as those mixed in family size. The specific gravity of the meringues was never as low as Glabau's (0.176). However, the specific gravity of Glabau's (48) batter, 0.31–0.34, was higher than that of Schrenk's (104), 0.23–0.29. Comparable cakes were made from each of the frozen whites, and those from the frozen whites were as desirable as those from fresh eggs. However, different beating times had to be used with each frozen white to obtain comparable results.

Pasteurization of egg white. Losses in cake volume (114) were noted when the egg white was heated as low as 40.5°C (105°F), if the egg white was held 6 hours or more at this temperature. The egg whites could be momentarily heated to 57.8°C (136°F) without appreciable loss of functional ability. But at 59°C (138°F) or above, heating had deleterious effects on whipping rate and cake volume, even when heating was nearly instantaneous and the white was immediately cooled. Sucrose and other sugars added to the egg white before pasteurization and drying exerted a protective action in that the pasteurizing temperature could be raised before the adverse effects of heat were noticeable. Lowering the pH of the egg white from 8.5 to 6.5 increased the stability to heat.

Formulas for angel cake. Barmore (11) reported from his investigations on baking angel cake at various altitudes that increasing the egg or flour, or both, in an angel cake increases its tensile strength. Conversely, increasing the sugar decreases the tensile strength or increases the tenderness. Barmore says that his formula

$$F - 0.43S - 0.41A - 24.5 = 0$$

gives all the possible recipes for this type of flour mixture for any habitable altitude. F represents flour in grams; S, sugar in grams; and A, altitude in thousands of feet. The egg white was kept constant at 210 grams, and the flour should be not less than 40 nor exceed 80 grams for this proportion of egg white. For 1 gram of egg white this allows 0.19 and 0.39 gram of flour, respectively. Formulas are given in Table 26.

The first six formulas have been made at 900-feet elevation. Excellent cakes may be made from the first five formulas at this elevation. Formula II is difficult to handle. Formula VI has too much flour for an altitude of 1000 feet. The last three formulas are from Barmore's (11) tables; VII and VIII are for 1000-feet elevation with the largest and smallest amounts of flour advocated, respectively; IX is for 5000 feet with the medium amount of flour. Further analysis of these formulas is found in Table 27.

TABLE 26

FORMULAS FOR ANGEL FOOD CAKE

Formula	Egg white		Sugar		Flour		Cream of tartar t	Amount of salt t
	Meas. cups	Wt. g	Meas. cups	Wt. g	Meas. cups	Wt. g		
I	1	244	1¼	250	1	100	1	¼
II	1	244	1½	300	1	100	1	¼
III	1½	366	1½	300	1	100	1½	½
IV	1½	366	1¼	250	⅘	80	1	¼
V	1¾	427	1½	300	1	100	2	½
VI	1	244	1	200	1	100	1	¼
VII	1	246	1⅙	235	⅘	80	1	¼
VIII	1	246	¾	141	⅖	40	1	¼
IX	1	246	¾	150	⅗	60	1	¼

TABLE 27

AMOUNT OF SUGAR AND FLOUR PER GRAM OF EGG WHITE AND RATIO OF SUGAR TO FLOUR (ANGEL CAKE)

Formula and source		Egg white g	Sugar g	Flour g	Ratio of sugar to flour
I	Standard	1	1.02	0.41	2.5
II		1	1.23	0.41	3.0
III	Thirteen egg	1	0.82	0.27	3.0
IV	Cederquist	1	0.68	0.23	3.0
V	Prize (I.A.P.I.) *	1	0.70	0.22	3.1
VI	Hunt and St. John	1	0.82	0.41	2.0
VII	Barmore (1000 ft)	1	0.95	0.33	2.9
VIII	Barmore (1000 ft)	1	0.57	0.16	3.5
IX	Barmore (5000 ft)	1	0.67	0.24	2.5

* Institute American Poultry Industries.

Since sugar tends to prevent coagulation of the egg white, there is an amount of sugar which, if exceeded, will prevent coagulation to such an extent that the cake is so tender it will fall. It is desirable to use an amount that will just prevent the cake from falling. However, this particular amount of sugar will depend somewhat upon the amount of flour. The flour increases the toughness of the cake. Hence there is a ratio of sugar to flour, so that, within certain limits, as the sugar is decreased the flour must also be decreased. For the formulas given the ratio of sugar to flour is 3 to 1 in four of the recipes and 2.5 to 1 in the standard recipe.

Factors contributing to the quality of angel cake. These factors start with egg quality. The foam, its texture, specific gravity, and stability are affected by the temperature of beating the egg, the extent of beating, the speed and type of beater. The amount of salt, sugar, and cream of tartar as well as the stage of beating at which they are added contribute characteristics. The flour, its kind, amount, and whether part or all of the sugar has been combined with the flour exerts its influence.

After the ingredients are combined, the cake batter may be divided and from this one mix cakes with different characteristics obtained by starting baking in a cold or preheated oven, baking in different ovens, at a given temperature for different periods of time, and at different oven temperatures.

The egg white foam. The volume of the cake depends not only upon the amount of air beaten into the egg but also upon maintaining this air during the baking. Thus, as Barmore states, there are two factors to be considered: first the increased volume by including more air, second the reduction in volume because of instability of the foam. The point at which these two factors are balanced will produce the largest cake volume.

See the section on egg white foams. With insufficient beating (Fig. 52, Experiment 46C) too little air is enclosed in the foam, so that during baking the expansion of the air and steam do not stretch the membranes around the cells to their full capacity. This results in a smaller cake volume and thicker, hence tougher, cell walls. With the optimum amount of whipping, which is less than the maximum volume to which the foam can be whipped, the cell walls are stretched to the limit in baking, but do not break. This results in a large volume and thin cell walls, thus a tender cake. With overwhipping the egg white more protein is coagulated at the air/egg surface. Thus the foam loses extensibility, the extent depending on the degree of overwhipping. When cooked, far too many cell walls break, resulting in loss of cake volume.

Specific gravity of the foam. It would seem that for experimental purposes the easiest way to duplicate results is to control the specific gravity of the foam and batter. To a certain extent this is true, for there is a close correlation between the specific gravities of the foam, batter, and cake, hence the cake volume. However, the specific gravity to which the foam should be beaten varies with the type of beater. For example, with a fine-wired whip, 0.09–0.11 may give the maximum cake volume whereas for a hand-

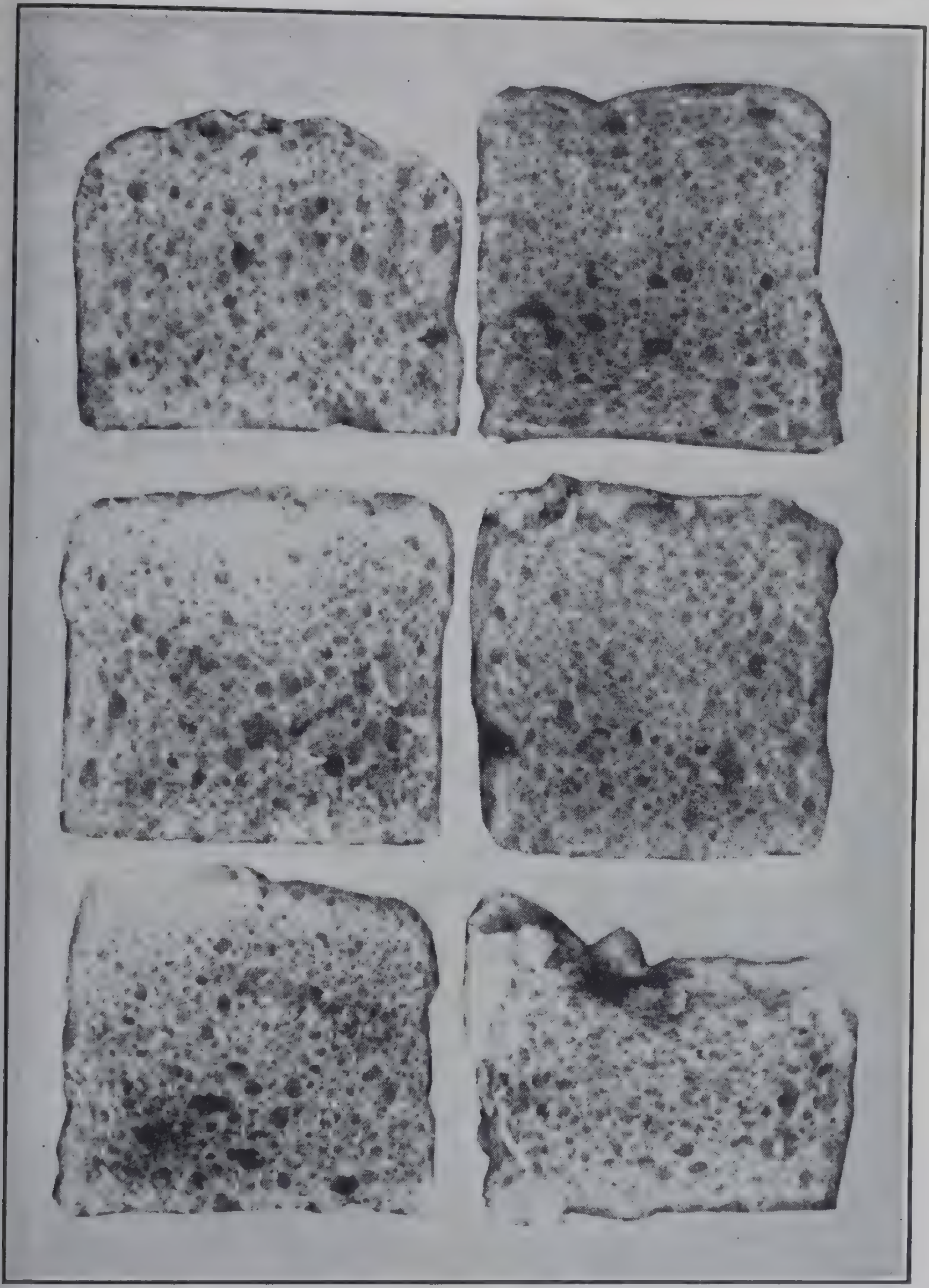


FIG. 52. Angel cake. Showing effect on volume and texture of beating the egg whites to different stages of stiffness. Experiment 46C and F. *Left,* 1.25 cups of sugar; *right,* 1.5 cups sugar.

Upper: Egg white slightly underbeaten.
Middle: Egg white beaten sufficiently.
Lower: Egg white overbeaten.

operated rotary beater a specific gravity of 0.15–0.17 may produce the best results.

Ingredients used in angel cake. *Flour.* Cake flour produces a more desirable cake than hard-wheat all-purpose flour. Cakes made from the all-purpose flour shrink and pull away excessively during the last of the baking period and while cooling. As a consequence the volume is smaller, the cake more compact, than similar cakes made with cake flour. Regardless of the student's technic in making the cake, the author has never seen opposite results. Surprisingly, the cake from the hard-wheat all-purpose flour is tenderer than expected. A larger proportion of sugar with all-purpose flour should give a better-balanced formula.

The amount of flour per gram of egg may vary from 0.2 to 0.4 gram. The smaller amount tends to give a more moist and tender cake, the larger a drier and less tender one.

Cream of tartar. Cream of tartar added to egg white increases its acidity. Flavone pigments, which are present in the flour, are colorless in acid or neutral, but yellowish or yellow-green in alkaline mediums. If cream of tartar is omitted from angel cake the color is yellowish, the texture coarse and poor, the cell walls thick, and the cake tough. The coarse texture is probably the result of lessened stability of the foam. Evidently the tartrate ion, in addition to stabilizing the foam, brings about peptization of the egg or flour proteins, or both, thus increasing the tenderness.

Sugar. Fine crystalline sugar, such as fruit or berry sugar, which dissolves rapidly is excellent for angel cake. The maximum amount of sugar per gram of egg white is about 1 gram. At higher altitudes this must be decreased. At sea level or 1000 feet above sea level, the sugar can be increased to 1.25 grams per gram of egg white provided that the maximum amount of flour is used. But it must be handled carefully. See Fig. 52. Cakes with large proportions of sugar have a typical sugary, crystalline, rather dry crust.

Mixing angel cake. Many experimental studies (122) have shown the following procedure to be good: The egg whites are beaten until foamy. Then the salt, cream of tartar, and flavoring are added early in the first quarter of whipping. Beating is continued. In the second quarter of whipping ¾ of the sugar is added for electrically operated beaters at high speeds. For hand-operated beaters the same amount of sugar is added gradually during the last half of whipping. Adding the sugar early increases the whipping time. This is an advantage with an electrically operated whip at high speed as the sugar also delays the overwhipping of the whites. A fourth of the sugar is sifted with the flour. This prevents the cake flour from rolling into balls as it is folded into the egg-white-sugar mixture. This procedure is nearly the same as that suggested by Barmore (11). The procedure can be varied considerably. Folding the sugar into the whipped egg white is an easy method of standardizing the procedure for class work. A foam in which the sugar can be folded (Figs. 53, lower left and lower right) 120 or 180 times is fairly stable, but folding should be done lightly. Mixing all the sugar and flour together before adding to the egg foam has not produced as satisfactory results as adding all or part of the sugar first. As one student remarked, "The addition of sugar to the egg white foam seems to prepare the egg for blending with the flour."

Texture. The texture and grain, also the volume and tenderness, of angel cake are influenced by several factors: (*a*) the mechanical treatment, which includes the kind of beater used, the degree of whipping of the whites, the method and extent of mixing the ingredients; and (*b*) the ingredients used, their amount and kind.

The factor determining the size of the cells to the greatest degree is the type of beater and the extent to which the egg white is beaten, which has been considered. Longer whipping produces more and smaller air bubbles so that the cells are smaller, the grain finer. Rotary and electric beaters, in general, give finer grain than whisks.

Longer mixing of the sugar with the egg whites tends to give a finer grain, but not to the extent that the folding of the flour does. See Figs. 53 and 54. Thus the grain or texture of the cake may vary to a certain extent, but a cake with thin cell walls and medium-sized cells that is so tender that it "melts in your mouth" is preferable to one that has a fine grain but is less tender.

Temperature of baking angel cake. There is no "best" temperature, as desirable cakes may be baked over a range in temperature. The upper and lower limits of temperature will, however, be determined by their effect on the cake. The upper limit would be that at which the crust is set so rapidly that the cake volume is reduced; the lower limit, that at which the cake structure is unduly long in setting. There is a "best" time of baking at a given temperature in relation to the volume and shape of cake pan.

Probably the easiest way to bake angel cakes to the same stage of doneness is to place a thermometer or thermocouple in the center of the cake and bake to the maximum interior temperature. For a given formula and altitude the interior temperature of the cakes, regardless of the oven temperature, is nearly the same. Continuing the baking too long after this maximum temperature is reached binds more water, increases the toughness, and the apparent dryness of the cake. However, there are some arguments in favor of the lower temperatures. If the data in Table 28 are studied, it will be noted that the toughening effect due to longer baking time at a given temperature, as shown by tensile strength, is greater at the higher temperatures. Leaving the cake in 5 minutes too long is not so serious at 150°C as at 170°C or higher.

The data of Kraatz (69) illustrate the effect of baking too long with consequent toughening, as shown by both scores and tensile strength, of the cake. She used the recipe given under Experiment 46, except that 90 instead of 100 grams of flour was used. Each cake mix was divided into

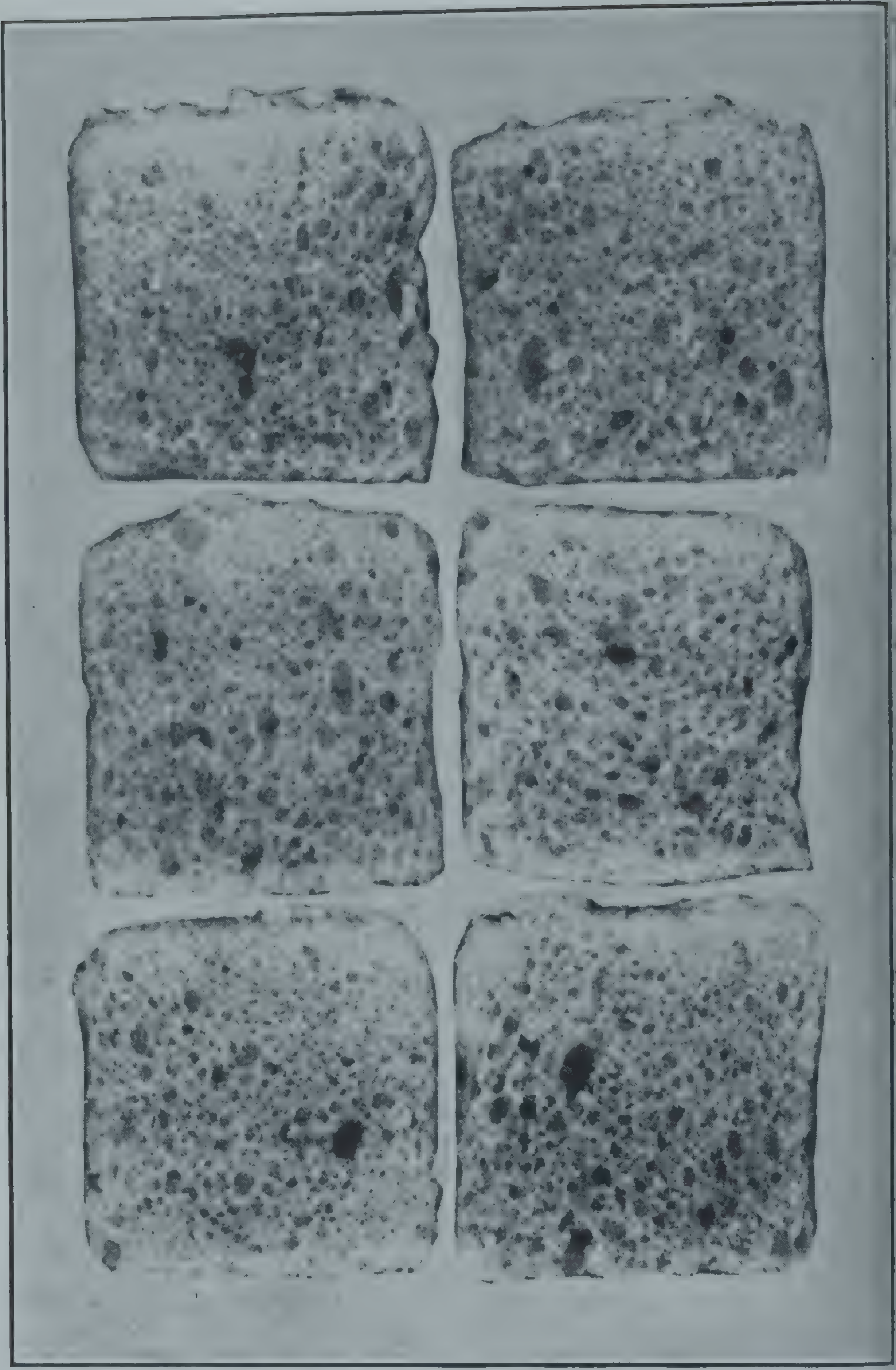


FIG. 53. Angel cake. Showing the effect on volume and texture of varying the folding of the sugar with the egg white. Experiment 46A.

Upper left: sugar folded 20 times; *upper right:* sugar folded 40 times.
Middle left: sugar folded 60 times; *middle right:* sugar folded 80 times.
Lower left: sugar folded 120 times; *lower right:* sugar folded 180 times.

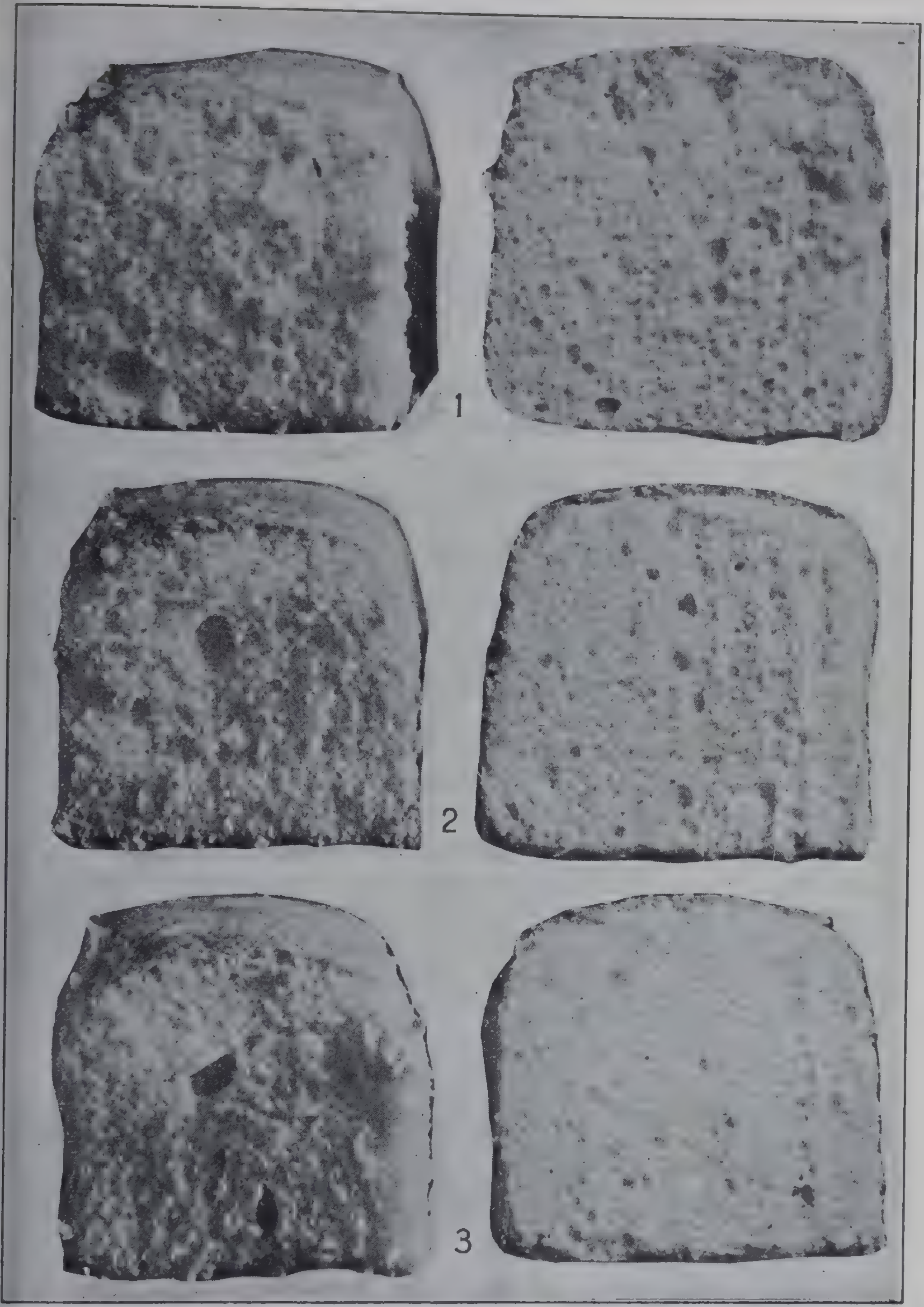


FIG. 54. Angel cake. Showing effect on volume and texture of varying the extent of folding the flour with the sugar and egg white. Experiment 46B. As shown in the illustration the cakes are about five-sixths actual size.

1. The flour folded 40 strokes.
2. The flour folded 60 strokes.
3. The flour folded 80 strokes.

TABLE 28

DATA FOR CAKES BAKED VARYING LENGTHS OF TIME AT THREE OVEN TEMPERATURES
(*Kraatz*)

Oven temperature	Baking time minutes	Scores			Tensile strength g	Volume cc	Specific gravity of cake	Volatile loss %
		Tenderness	Moistness	Eating quality				
150°C	45	24.0	12.2	30.3	33.6	666	0.176	13.2
	50	23.5	12.1	30.2	36.7	675	0.172	14.2
	55	22.3	11.8	28.7	40.8	676	0.169	15.2
	60	21.6	11.6	28.7	40.1	680	0.167	16.0
160°C	30	24.6	12.3	32.0	26.1	674	0.178	11.2
	35	23.6	12.2	31.2	30.3	674	0.170	12.3
	40	21.6	11.9	29.2	32.9	691	0.169	13.5
	45	21.1	11.8	28.6	36.9	699	0.165	14.5
170°C	25	24.8	12.1	31.2	28.5	682	0.178	10.2
	30	23.3	12.2	30.2	34.2	697	0.172	11.5
	35	22.1	12.1	29.2	42.6	696	0.169	13.1
	40	21.3	11.7	27.6	43.0	711	0.162	14.6

Highest possible scores, tenderness = 30, moisture = 15, eating quality = 40.

four parts and baked in slightly flaring loaf pans. The highest-scoring cakes were those baked the shortest time at each temperature in spite of the fact that the cakes had slightly larger volume with longer baking. The times of baking gave differences in results which were highly significant for all data in Table 28, except for scores for moistness. A few cakes baked at 150°C indicated that at least 10 minutes' longer baking was required at this temperature for full-sized cakes.

Sponge Cake

Review of literature on sponge cake. *Temperature of beating the eggs.* Glabau (44), along with other studies on sponge cake, varied the initial temperature of the whole eggs in the same manner as for angel cake. The best cakes of Glabau's series were those in which the egg was heated to 32.2–46.1°C (90–115°F) at start of beating. The time of beating the egg-sugar foam to a specific gravity of 0.217 varied from 15 minutes at 4.4°C (40°F) to 7 minutes at 26.7°C (80°F). The eggs at 1.7°C (35°F) never reached a lower specific gravity than 0.24, even after 24 minutes of beating.

Quality of eggs. Physical and chemical measurements (66) were made to determine the egg quality, the CO_2 content of the white and yolk, the *p*H and total solids of white, yolk, and magma, and the viscosity of the magma. These physical and chemical measurements showed no definite relationship to the cake quality as determined by the specific gravity and *p*H of the cake batter, the cake volume, the tensile strength, and the compressibility of the cake crumb. A second study (67) using the same tests on the eggs and on the cake showed that five different diets of the hens did not affect the properties of eggs or quality of the cake made from them. It was also found that no progressive change in the properties of the eggs or the quality of the cakes occurred over a 7-month period in the laying cycle of the hen or the seasons of the year studied (December through June).

On the other hand, Pyke and Johnson (99) have presented data which show "that high-quality eggs yield better cakes of greater volume than do low-quality eggs," for sponge cakes and also those made with shortening. They state that the coagulation temperature of egg proteins is elevated as the eggs detriorate.

Tests. Platt and Kratz (97) developed tests for measuring and recording characteristics of sponge cake.

Altitude. Pyke and Johnson (99), keeping the sugar content constant in order to provide satisfactory sweetness, have developed sponge cake formulas for altitudes from sea level to 12,000 feet. As the altitude increases the flour and water are increased. Increase of water permits coagulation of the egg protein and gelation of the starch. The accurate way to insure the incorporation of the amount of air sufficient for leavening at each altitude is to control the specific gravity of the batter. This should be greater at higher altitudes.

Baking temperature. James (62) baked sponge cakes at 150°, 160°, 170°, and 180°C for varying periods of time. The results showed an optimum baking time at each temperature, with tougher, less desirable cakes when the optimum time was exceeded.

Dried egg. A severe test of egg quality is its ability, when whipped into a foam, to aerate and produce an acceptable sponge cake. Because of this, sponge cake has been used extensively to test the functional properties of whole egg powders. It was soon found that most whole egg powders, when reconstituted and whipped at room temperature, did not produce a foam stable enough to obtain acceptable sponge cakes. Then a group of English workers (12, 53) reported that, by adding the sugar and water to the egg powder, and surrounding the container with a water bath at 38–50°C (100–122°F), a stable foam could be produced. Next, with a badly deteriorated spray-dried egg powder of 5% moisture content, it was found (84) that a satisfactory foam and sponge cake were obtained by combining the meringue ingredients, slowly heating them to 68°C, and surrounding the electric mixer bowl with a water bath at 80°C. Freshly prepared spray-dried whole egg powders of less than 2% moisture content, which were obtained from three different plants operated by one firm, varied in initial quality as shown by extent of denaturation of the proteins, ease of foam formation, cake volume, and cake quality. One of these powders and a powder dried from the frozen state under vacuum produced cakes comparable in quality to those made from fresh shell eggs.

Jordan and Pettijohn (65) found that beating the foam of a spray-dried whole egg powder for sponge cake at 60°C produced a better cake than when the powder was beaten at room temperature. Addition of cream of tartar increased the tenderness of the cake.

Procedures that improve the solubility and stability of whole egg powder improve its functional behavior in sponge cakes.

Pasteurization (48, 83) of egg magma, if not too long or at too high a temperature, does not injure its quality for sponge cake.

Factors affecting the quality of sponge cake. If the ingredients are well balanced, the quality of the sponge cake depends chiefly upon the beating of the egg and sugar. The sugar and egg magma may be whipped together to a foam, or the sugar and yolks may be whipped, the beaten whites being folded in after the flour has been added. Other factors affecting the cake quality are the mixing and baking.

Probably the most common fault in making sponge cake is insufficient beating of the egg yolks and sugar. These two ingredients, plus the liquid, if water or lemon juice is used, can be beaten until they are extremely light and foamy. This is most successfully done with rapid beating, preferably by an electrically operated beater or a rotary beater rather than a whisk. Excellent sponge cakes may be made from the yolks alone, provided that some water is added and the yolks and sugar are beaten rapidly until very light. In the type of sponge cake recipe given in Experiment 47, when the flour is mixed too long with the sugar and egg yolks the cake is more compact and tough. But in some types of sponge cake in which considerable water is added, that is, the ones called water sponge, it is often necessary to beat the flour and egg yolks a long time to obtain a cake with thin cell walls and a uniform texture. In other words, this can be interpreted to mean that, for each recipe in which the proportion of ingredients varies from those in another recipe, the amount and the kind of manipulation to produce a cake of the best texture vary.

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EGGS

Cooking Eggs in Water

Experiment 40.

I. In the shell.

A. To determine the effect of coagulation at different temperatures on the texture of the white and yolk.

1. Cook an egg in water. Do not let the temperature of the water go above 72°C. It is easier to control the temperature if a large quantity of water is used and the heat is turned low after the desired temperature is reached. Cook from 1 to 1¼ hours.

2. Cook an egg in water the temperature of which does not go above 85°C. Cook 30 to 35 minutes.

3. Cook two eggs in boiling water. Cook 12 to 15 minutes.

a. Cool one egg slowly, leaving it in the water in which it was cooked.

b. Cool the other egg rapidly, letting cold water from faucet run over it until cold.

Compare with the eggs from 1 and 2 in texture and firmness of the white and yolk. Which gives a tender and desirable product for eating? For slicing? Do any have a green layer at the junction of the white and yolk?

B. To determine the effect of cooking for varying lengths of time at a high temperature upon the texture and consistency of egg white and yolk.

Cook in boiling water. Vary the time of cooking as desired. The following times are suggested: 1, 2, 3, 5, 7, and 10 minutes.

Compare the consistency of the white and yolk cooked for varying lengths of time. Compare with results obtained in A.

II. Out of the shell.

To determine the method of obtaining a desirable poached egg.

Use a pan deep enough so that water will entirely cover the egg. Add a pint of water. Use more water if necessary, but all should use the same quantity. A film of fat rubbed over the bottom of the pan before the water is added seems to help prevent the egg from sticking to the pan. Have the water boiling when the egg is added. Keep the water bubbling very slowly. (For edible purposes it is better to keep the water below the boiling point after the egg is added, but the temperature of the water in different pans may vary widely. Hence, keeping the water boiling very slowly serves for comparative purposes.) Cook 3 minutes. Start with fresh water for each experiment. Break the egg into a sauce dish just before adding to the water. Slide it carefully into the water. Study the structure of one egg after it is broken out of the shell. Note the proportion of thick and thin white, for this will vary with different eggs. If very different in some individual eggs, cook and repeat one part of the experiment, to see if you get the same results the second time. Note the chalazae. Do any spots appear on the yolk?

A. Fresh eggs.

1. Cook in plain water.

2. Add ¾ teaspoon of salt per pint of water.

3. Add 1 teaspoon of vinegar per pint of water.

4. Decide which of the three experiments above gives the best-appearing product, then repeat it; but swirl the water around the pan, dropping the egg in the center.

B. Eggs deteriorated so that they have a larger proportion of thin white.

Repeat II A, 1, 2, 3, and 4.

C. Repeat A1, using a ring placed in the bottom of the pan in which the egg is placed. Or use any type of cup made for poaching eggs.

Which coagulates better, the thick or thin portions of the egg white? What is the effect of adding salt? Vinegar? Would the technic in swirling the water make any difference in the result? Why not swirl too hard? If eggs are cooked at a lower temperature, should the time be increased?

Do you wish to try changing the proportion of salt? The time and temperature of cooking?

Custards

Experiment 41.

To determine the factors that affect the coagulation and curdling of custards.

Recipe:

Milk	1 cup	244 grams
Egg	1	48 grams
Sugar	2 tablespoons	25 grams

A. To determine the effect of rate of coagulation upon the texture and consistency of custards.

1. Prepare 2 times the recipe, then divide into equal parts; use part 1 for A1, and part 2 for A2. It is better for two or more students to work together for this experiment. Combine all the ingredients and mix thoroughly. Put one part in the upper part of a double boiler. The boiler should be rather deep to have the custard sufficient to cover the thermometer bulb when portions of the custard are removed. A double boiler holding a quart and about 4 inches in depth is satisfactory. The custard should come well above the bulb of the thermometer even after the samples are removed. Add a pint of cold water to the lower part; then put the upper portion of the double boiler into the lower. Make a record of the temperature of the custard mixture and the time. Put over the fire and heat. The heating may be rapid until the custard mixture reaches a temperature of 70°C. The heat should be regulated so that 3 or more minutes is required to elevate the tem-

perature 1°C; *i.e.*, about 6 minutes should be required for the temperature of the custard to go from 80° to 82°. One student may hold the thermometer and read the temperatures; a second can record the time and temperature. Record the time every 5° during the first period of heating, *i.e.*, 30°, 35°, etc. But record the time for 1° rise after 78° is reached, i.e., at 78°, 79°, 80°, 81°C, etc. A third student may stir the custard and a fourth can remove portions of it. It is easier to let the bulb of the thermometer touch the bottom in the center of the double boiler. Use a wooden spoon for stirring. Have dishes ready to put the custard in. Bend the bowl of an old metal spoon until it is at right angles to the handle. Use it for removing portions of the custard, taking out 2 tablespoons at each temperature. Remove portions of the custard at 78°, 80°, 82°, 84°, 86°, 88°, and when curdled.

2. Repeat A1, but have the pint of water in the lower part of the double boiler boiling when the upper part is added. Regulate the heat to keep the water boiling very rapidly. Cook as quickly as possible, but not more than 6 minutes should be necessary. Record the temperature of the custard and the time just before putting the custard over the boiling water. If possible, record the temperature as under A1. The stirring should be rather rapid for the cooking is rapid. It will also take rapid work to remove the custard at the desired temperatures. Remove portions of the custard at temperatures given under A1.

Note the temperature before and during curdling of the slowly and rapidly cooked custards.

Does the temperature lag or drop in some instances? Prepare a time-temperature chart, showing the period of time required for custard for different groups and time intervals as follows. It will be found that the consistency of a given custard at a definite temperature, say 80°C, is directly proportional to the time required to heat it from 76° to 80°C. Compare thickening of custard for different groups, noting time required for each custard to reach a definite temperature. Also note curdling temperature and highest temperature reached.

Compare the consistency of the custards at each temperature. What is the effect of the rate of coagulation upon the amount coagulated at a definite temperature? Would you advise the rapid or the slow cooking? Why? Compare with baked custards heated to the corresponding temperatures.

B. Baked custards: To determine the effect of varying the proportion of ingredients in baked custard.

Prepare 2 times the recipe. Combine all the ingredients and mix thoroughly. Divide into 5 portions, using equal parts in each cup. Put all the cups in a large, flat pan. Set the pan in the oven. By supporting on an oven rack above the custards insert a right-angled meat thermometer, so that the bulb of the thermometer is at the center of one custard. Place a second thermometer so that the temperature of the water can be read. Start heating the oven, and then pour boiling water around the custard cups until it comes as high as the custard in the cups. If the oven has a regulator so that a low temperature, 125–150°C (250–300°F), is maintained, the custards can be cooked without adding the water to the pan. Record the time and the temperature of the custard every 3 minutes if the oven has a glass door.

otherwise every 5 minutes. Remove one custard of each series at the following temperatures: 80°, 82°, 84°, 86°, and 88°C.

If possible bake all the custards in the same pan.

1. Use 1 egg, 1 cup of milk, 2 tablespoons of sugar.
2. Use 1 egg, 1 cup of milk.
3. Use 1 egg, 1 cup of milk, 4 tablespoons of sugar.
4. Use 1½ eggs, 1 cup of milk, 2 tablespoons of sugar.

Are all the custards for the same experiment of the same thickness or consistency? How might you account for this? Are the custards removed at 82°C all of the same consistency? Compare the time required for cooking. Does the increased egg result in a thicker custard than when 1 egg is used? What is the effect of increasing the sugar? Which proportion of sugar is desirable for serving? Are any of the custards curdled? What is the optimum temperature for serving each custard?

C. To determine the effect of substituting yolks or whites for the whole egg.

Follow directions under B. Prepare 2 times the amount given below.

1. Use 2 yolks (36 grams), 1 cup of milk, 2 tablespoons of sugar.
2. Use 2 whites (60 grams), 1 cup of milk, 2 tablespoons of sugar.

Beat the whites only slightly before adding the milk. If beaten stiff they float on top of the milk and do not blend well with it. Also fill the cups to the same height as those containing the egg-yolk custard. Otherwise the larger quantity of egg-white custard will heat more slowly than the egg-yolk custard.

When egg yolks are substituted for the whole egg in the custard, compare the stiffness of the custards with those made from the whole egg cooked to the same temperature. Compare the flavor. The color. Compare with custards made of egg white.

D. To determine the factors that affect coagulation.

Prepare ½ the recipe, using only 1 custard cup.

1. Use 1 egg, 1 cup of distilled water, 2 tablespoons of sugar.
2. Use 1 egg, 1 cup of distilled water, 2 tablespoons of sugar. Dissolve 0.3 gram of calcium chloride in the distilled water before adding the egg and sugar.
3. Use 1 egg, 1 cup of distilled water (reserve 1 tablespoon of water to dissolve the $CaCl_2$), and 2 tablespoons of sugar. Bake with rest of custards under D. After removal from the oven note consistency of the custard mix, then add the water in which 0.3 gram of $CaCl_2$ has been dissolved. Stir as little as possible. Let stand 1 minute then observe.
4. To 1 egg, 1 cup of distilled water, and 2 tablespoons of sugar add $FeCl_3$. Mix a very small amount (about 0.09 gram) of the $FeCl_3$ with the distilled water. If no accurate scale is at hand, add just enough $FeCl_3$ to the water to give it a slightly yellow color when the glass containing the water is set over white paper. What happens when the egg is stirred into the mixture? Continue stirring for a few seconds.
5. Repeat D1, but add about ⅛ teaspoon of ferric chloride. What happens when the egg is added to the $FeCl_3$ solution? Does the custard coagulate during cooking? Test the custard mix with litmus paper.
6. Repeat D1, but add 1 gram of NaCl.

7. Repeat D1, but add 0.5 gram of an Osborne and Mendell (or Sherman, or Steenbock) salt mixture commonly used in small animal feeding experiments.

8. Repeat D1, but add ¼ teaspoon of lemon juice.

9. Repeat D1, but add ½ teaspoon of lemon juice. Vinegar may be substituted for the lemon juice.

E. To determine the effect of beating on thickening power of the egg.

1. Use 2½ eggs. Beat in a bowl either by hand or with an electric mixer until the yolks and whites are well blended. Weigh out 48 grams, and combine with 1 cup of milk and 2 tablespoons of sugar.

2. Beat the egg remaining from part E1 until thoroughly beaten. The egg can be beaten as long a period as desired. Weigh 48 grams of the egg. Discard the remaining egg. Combine the 48 grams with 1 cup of milk and 2 tablespoons of sugar. If the egg was beaten with an electric mixer, put milk in the mixer bowl and combine with the mixer. Does the egg tend to float on top of the milk? Bake according to directions under B.

3. Beat 1 egg slightly, so that the yolk and white are not well blended. Add to 1 cup of milk and 2 tablespoons of sugar.

F. To determine the effect of egg quality upon thickening power of the egg.

1. Repeat B1, using eggs 1 day or less in age.

2. Repeat B1, using eggs that have been stored at room temperature for about 2 weeks.

What is the effect of increasing the egg upon temperature of coagulation? Of varying the proportion of sugar? Does the distilled-water custard set? What is the effect of adding calcium lactate? Salt? What is the reaction of the custard containing the small proportion of aluminum or ferric chloride? The one with the larger proportion? Does either set? Unless the proportion of ferric or aluminum chloride is small enough, D4 may not set.

Salad Dressings

Experiment 42.

To determine the effect of acid upon coagulation of egg in cooked salad dressings.

Recipe:

Egg yolks	4	72.0 grams
Sugar	½ tablespoon	6.2 grams
Liquid total	1 cup	240.0 grams
Mustard	½ teaspoon	
Salt	¼ teaspoon	

A. Cook in a double boiler. Follow directions under Experiment 41A for cooking. It is not necessary to cook as slowly as under Experiment 41A, but the time for each degree rise in temperature should be the same in all the experiments.

Remove portions of the salad dressing at the following temperatures: 76°, 78°, 80°, 82°, 85°, and 92°C. Note the temperature when the salad dressing coats the spoon.

1. Use ⅛ cup of vinegar, ⅞ cup of water.
2. Use ¼ cup of vinegar, ¾ cup of water.
3. Use ½ cup of vinegar, ½ cup of water.
4. Use ⅛ cup of lemon juice, ⅞ cup of water.
5. Use ¼ cup of lemon juice, ¾ cup of water.
6. Use ½ cup of lemon juice, ½ cup of water.
7. Repeat A1, but add 1 tablespoon flour, 7 grams.

At which temperature is the most desirable texture for a salad dressing obtained with the different proportions of acid? Which proportions of acid give the thicker salad dressing? Does curdling occur at the higher temperatures? From results with custard, what would be the result of increasing the proportion of salt? Which produces the clearer salad dressing, vinegar or lemon juice?

Hollandaise Sauce

Experiment 43.

To determine the factors affecting the smoothness of Hollandaise sauce.

Recipe:

Butter	½ cup	112 grams
Egg yolks	4	72 grams
Hot water	⅓ cup	80 grams
Vinegar	1 tablespoon	15 grams
Salt	¼ teaspoon	1 gram

1. Use half of the recipe:

Melt the butter in the top part of a double boiler. Remove top part of double boiler from heat. Add egg yolk that has been beaten well but is not foamy. Stir until well blended. Add warm water, about 70°C, and stir. Add vinegar and stir. Put top part of double boiler over bottom part. The water in lower part of double boiler should be about 70°C (185°F) or lower. Record time at start of cooking. Heat very slowly. Cook, stirring constantly. When the sauce begins to thicken the temperature remains constant for a time. Remove from the heat just as the temperature starts to climb. This gives time for maximum thickening. Curdling and separation will occur soon afterwards. Record time and temperature. Stir until the sauce is shiny.

2. Use full recipe. Repeat 1, but remove a sample when the temperature becomes constant and another when the temperature starts to climb. Have the samples large enough for all the class to observe and taste. Record time and temperature. Cook the remainder until curdled. Remove a sample of the curdled sauce. Record time and temperature. To the curdled sauce in the double boiler, add a teaspoon or less of warm water and beat. If emulsion does not reform, repeat.

3. Repeat 2, but increase the egg to 108 grams.

4. Repeat 2, but substitute 15 grams of lemon juice for the 15 grams of vinegar.

Omelets

Experiment 44.

To determine the factors that affect the texture of omelets.

Recipe:

Egg	1		Salt	⅛ teaspoon	
Liquid	1 tablespoon	15 cc	Butter	½ tablespoon	7 grams

Directions for mixing and baking.

The first omelets should not be used for comparisons of experiments. The omelets should be made over several times if necessary to acquire the technic and the manipulation necessary to make a good omelet.

Separate the white and the yolk of the egg. Beat the yolk until it will mix well when folded in the white. Beat the white until it is frothy, and add the liquid; add the salt and continue beating until it is quite stiff. It should be beaten until it will stay in an inverted bowl.

Mix the beaten white and yolk by folding. Use a spatula for folding. The spatula should have a flexible blade near the end but should be rigid where it joins the handle. Fold by holding the blade of the spatula parallel to the right side of the bowl. Move to the bottom of the bowl, at the same time pressing so that the spatula scrapes the material from the bottom of the bowl. Bring up with the blade parallel to the left side of the bowl. As the spatula is brought across the top of the material turn it upside down. Turn the bowl occasionally, and about every fifth stroke bring the spatula up through the middle of the material for better mixing. Fold white and yolk until well blended. They should not be mixed until a large portion of the air is lost from the white, but they must be mixed enough to prevent separation of the white and yolk. Count the number of strokes used in mixing the yolk and white. The number needed will vary with the size and kind of utensil, usually about 20 to 25. The same number of strokes should be used in mixing for all the experimental work and also the same size and kind of utensils. If desired, different makes and styles of egg beaters and whisks can be used. Count the motions required to beat the egg whites to the same degree of stiffness. The butter is put in a frying pan or an omelet pan of the proper size for a one-egg omelet. Melt the butter in the pan. Add the omelet and cook over a medium flame for about ½ minute before placing in the oven. Have the temperature of the oven 160–165°C (320–330°F). Oven baking is not necessary but it gives a uniform temperature for class work. Bake 25 minutes. If necessary, increase or decrease the time of baking.

A. To determine the effect of omitting the liquid and the effect of using different liquids.

1. Omit the liquid in the recipe.
2. Use water for the liquid in the recipe.
3. Use milk for the liquid in the recipe.
4. Use tomato juice for the liquid in the recipe.
5. Use 1 teaspoon of lemon juice and 2 teaspoons of water for the liquid in the recipe.

B. To determine the effect of omitting the liquid and the effect of using different liquids and different proportions of these liquids.

1. Omit the liquid in the recipe.
2. Make three omelets, using 5, 10, and 15 cc of water in the recipe.
3. Use 15 cc of milk in the recipe.
4. Use 15 cc of tomato juice in the recipe.
5. If there is time make a series of omelets using 1, 2, and 5 cc of lemon juice plus water to make 15 cc of liquid.
6. Repeat A5, but use vinegar.
7. Use 0.25, 0.5, and 0.7 gram cream of tartar, with and without 15 cc of water. Add the cream of tartar after the egg white has been beaten until it is frothy.
8. Use 5 and 10 cc of grapefruit juice plus water to make 15 cc of liquid.
9. Use 5 and 10 cc of orange juice plus water to make 15 cc of liquid.

If possible determine the *p*H of the acid-liquid mixture and of the omelet mixture.

C. To determine the effect on the volume and texture of combining the liquid with the egg yolk.

Repeat the series under A1. If time is short repeat the one under A in which a foam is not obtained with the liquid and egg white.

D. To determine the effect of cooking at different temperatures.

1. Repeat A2, using 15 cc of water, and bake at 160°C (320°F) for 28 minutes.
2. Repeat C1, but bake at 175°C (350°F) for 23 minutes.
3. Repeat C1, but bake at 150°C (300°F) for 32 minutes.

E. To determine the effect of beating the egg white to different stages of stiffness on the texture and the volume of omelets.

1. Repeat A2, using the proportion of water found best for a control.
2. Repeat D1, but beat the egg white until very dry and flaky.
3. Repeat D1, but do not beat the egg white as stiff as for the control.

Meringues

Experiment 45.

To determine some of the factors affecting the desirability and texture of meringues.

I. Soft meringues.

Recipe:

Egg whites	2	60 grams
Sugar	4 tablespoons	50 grams
Water (may be omitted)	2 teaspoons	
Salt	1/16 teaspoon	
Vanilla	1/4 teaspoon	

Directions for mixing.

Beat the egg white until foamy, 50 turns of handle of rotary beater. Add the water, salt, vanilla, and beat an additional 100 turns with rotary beater. Add sugar and beat 50 turns with rotary beater. (*Note.* The sugar may be added gradually. If added in this manner, the amount of beating after addition of salt should be shortened. Ask instructor for directions. Change or adapt the extent of beating to suit the type of beater used, whether water is added, and the consistency of the egg white.) The above quantity of meringue should give enough for 4 pies about 6 inches in diameter. The meringues should be between ¾ and 1½ inches in depth. Bake pastry. Fill shells with chocolate, lemon, or butterscotch filling as desired. Spread the meringue carefully over the filling to the edge of the crust, leaving it somewhat rough over the top. The meringue may be placed on a hot or cold filling. However, if added to a cold filling the time for baking will be longer, especially at the lower temperatures. When possible keep portions of the pie overnight to observe the extent of leakage of the meringue.

A. Temperature of baking.

1. Bake at 230°C (450°F) for 4 minutes.
2. Bake at 215°C (420–425°F) for 6 minutes.
3. Bake at 200°C (about 400°F) for 8 minutes.
4. Bake at 185°C (365°F) for 12 to 15 minutes.
5. Bake at 155°C (about 300°F) for 25 to 30 minutes.

B. Amount and kind of sugar.

Bake at temperature found best under A.

1. Use 1 tablespoon (12.5 grams) sugar per egg white.
2. Use 1½ tablespoons (18.5 grams) sugar per egg white.
3. Use 2 tablespoons (25 grams) sugar per egg white.
4. Use 2½ tablespoons (31 grams) sugar per egg white.
5. Repeat B3, substituting powdered sugar for the granulated sugar.
6. Use 1 tablespoon honey or sirup per egg white.

C. Extent of beating after sugar is added.

Bake at temperature found best under A, and use amount of sugar found best under B.

1. Beat 25 turns of handle of rotary beater after sugar is added.
2. Beat 50 turns after sugar is added.
3. Beat 75 turns after sugar is added.
4. Beat 100 turns after sugar is added.
5. Fold in sugar with spatula, using 50 folds.

D. Time of adding sugar to egg white.

Bake at temperature found best under A, and use amount of sugar found best under B. Beat until foamy, add sugar, and cook as indicated.

1. Add sugar and water (if used) at first and beat until shiny and stiff. Beat 200 turns of beater handle. Remove ¼ of mixture for D1.

2. Beat the mixture remaining from D1 250 turns of the beater handle. Remove ¼ of original mixture for part 2.

3. Beat the meringue remaining from D2 300 turns. Use ¼ of the original mixture for part 3.

4. Beat the remaining meringue 300 turns.

Repeat the above series. Beat egg white until foamy. Add water (if used) and start adding sugar gradually. Beat until stiff.

II. Hard meringues.

Recipe:

Egg white	1	30.0 grams
Sugar	4 tablespoons	50.0 grams
Cream of tartar		0.5 gram
Vanilla	2 cc	
Salt	pinch	

Directions.

The amount of beating will need to be worked out for the type of beater used. As a starter, try turning the handles of the beater 50 times, add salt, vanilla, and acid ingredient; continue beating, 25 turns of handle; add ¼ of the sugar, turn handle of beater 25 times. Repeat until all the sugar is used, turning handle of beater 35 to 50 times after addition of last sugar.

Bake on heavy white paper.

A. Temperature of baking.

1. Bake at 125°C (250°F) from 1 to 1.5 hours.
2. Bake at 135°C (275°F) for 1 hour.
3. Bake at 125°C (250°F) for 1 hour, turn off heat, and let cool in oven.
4. If you have a well-insulated oven, put meringues in preheated oven, turn off heat immediately, and leave overnight.

B. To determine the effect of kind and amount of acid ingredient.

1. Increase the cream of tartar to 0.7 gram.
2. Decrease the cream of tartar to 0.3 gram.
3. Substitute 2 cc of vinegar for the cream of tartar.
4. Substitute 4 cc of vinegar for the cream of tartar.

Angel Cakes

Experiment 46.

To determine the factors that affect the texture of angel cake.

Standard recipe:

Egg whites	1 cup	244 grams
Sugar	1¼ cups	250 grams
Cake flour, about	1 cup	90 grams
Cream of tartar	1 teaspoon	3.6 grams
Salt	¼ teaspoon	

Directions for mixing and baking.

Bake ⅙ of the recipe for each experiment. Beat the egg whites until frothy, then add cream of tartar and salt. Continue beating until they are the desired stiffness. The peaks formed when the white follows the lifted beater stand up fairly stiff and the tip end is slightly rounded. Sift the sugar to remove lumps and large crystals so that it will dissolve readily when mixed with the egg white. The sugar is sprinkled over the top of the egg and then folded in with a spatula. See Experiment 44 for directions for folding. The class should use spatulas of the same size. An egg beater can be used to fold in the sugar, but if used all members of the class should use one, and the number of strokes may need to be changed according to the size of the egg beater. The flour is sifted to remove all lumps so that it folds in readily with the mixed whites and sugar. If the sifter is a coarse one, sift the flour several times. The flour is sifted over the eggs, then folded in. Flavoring is omitted in the above recipe so that the flavor of ingredients is more distinct. When used it may be added with the cream of tartar, thus preventing excess folding. To better compare the effect of other factors it is preferable to beat the egg whites together and then divide after they are beaten. Pans 2½ by 2½ by 5 inches will hold ⅙ of the above recipe. It is better to bake the whole recipe in a pan with an opening in the center to facilitate baking, but small portions bake well in a loaf. Let the baked cakes hang inverted in the pans until cool.

A. To determine the amount of mixing of sugar to yield the best texture and volume.

Beat enough whites at one time for the whole recipe. Add the cream of tartar and salt. Divide into 6 parts, using 38 grams of the beaten white for each ⅙ of the recipe. Bake at 175°C (347°F). There should be several girls in this group. One girl should beat and weigh the egg whites. Each girl should do the same manipulation on each cake. Thus if one girl folds the first ¼ of the sugar, she should do this operation on each cake, but no more, and pass it on to the next girl. Two girls can fold the flour, the first adding ⅗ and the other the remainder.

1. Add approximately ¼ of the sugar, sprinkling it over the top of the beaten egg. Fold 5 times with a spatula. Repeat for each ¼ of the sugar. This gives a total of 20 strokes for folding in all the sugar.

Sift approximately ⅕ of the flour over the egg and sugar mixture. Fold with 5 strokes of spatula. Add another ⅕ of the flour, and fold a total of 10 strokes with the spatula. Add ⅕ of the flour, and fold a total of 15 strokes. Add ⅕ of the flour, and fold a total of 20 strokes. Add the last ⅕ of the flour, and fold a total of 40 strokes.

2. Repeat 1, but fold each ¼ of the sugar 10 times with the spatula.
3. Repeat 1, but fold each ¼ of the sugar 15 times with the spatula.
4. Repeat A1, but fold each ¼ of the sugar 20 times.
5. Repeat A1, but fold each ¼ of the sugar 30 times.
6. Repeat A1, but fold each ¼ of the sugar 45 times with the spatula.

What is the effect on the size of the cells and cell walls when the sugar is sufficiently mixed? When it is overmixed? When it is insufficiently mixed? Can the flour be blended well if the sugar has not been sufficiently mixed? What is the effect on the texture and tenderness of longer mixing?

B. To determine the amount of mixing of flour to give the best angel cake.

Beat enough eggs at one time to make ½ of the full recipe. Add cream of tartar and salt for ½ the full recipe. Divide the beaten egg white into three parts, using 38 grams for each part. Use either the standard or meringue method of adding the sugar, with number of strokes found best under A. Divide the work so that each girl does the same manipulation on each cake.

1. After adding the sugar, add the flour. Fold in with 40 strokes. Follow directions for folding flour under A1.
2. Repeat B1, but use 10 strokes to mix each ⅕ of the flour and a total of 60 strokes.
3. Repeat B1, but use 15 strokes to mix each ⅕ of the flour and a total of 80 strokes.

What is the effect on the grain, the volume, and the tenderness of the cake when the flour is mixed too long? Can less than 35 strokes be used?

C. To determine the effect of beating the egg whites to different stages of stiffness on the texture of the angel cake.

Beat enough egg whites at one time to prepare ½ of the full recipe. Add cream of tartar and salt for ½ the full recipe. The first portion is to determine the effect of too little beating of the white so that the egg white can be weighed with as little beating as desired. Weigh out 38 grams of the beaten white and use the remainder for 2 and 3. Divide the work so that each girl does the same operation on each cake.

1. Add ¼ of the sugar. Add each ¼ of the sugar with the number of strokes and method found best under A. Fold the flour with the number of strokes found best under B.

2. Continue beating the egg white from C1, until it is about the same stiffness as that used under A and B. Weigh out 38 grams.

Add the sugar and the flour as in C1.

3. Beat the remaining egg white from C2, until it is very stiff, dry, and flaky. Weigh out 38 grams. Add the sugar and the flour as in C1.

Would longer mixing of the egg white in C1 partially overcome the lack of sufficient beating of the egg whites?

D. To determine the effect of varying the proportion of cream of tartar used in angel cake, and the method of adding the cream of tartar.

1. Prepare ⅙ of the recipe for a control. Add the sugar by method and number of strokes found best under A and the flour with the number of strokes found best under B.

2. Repeat D1, but omit the cream of tartar.

3. Repeat D1, but increase the cream of tartar to 2 teaspoons for the full recipe.

4. Repeat D1, but omit adding the cream of tartar to the egg. Sift the flour and the cream of tartar together 2 or 3 times before adding the flour to the egg and sugar mixture.

E. To determine the effect of increasing the proportion of sugar used in the cake. (Formula II, Table 26.)

1. Increase the sugar for the full recipe to 1½ cups. Beat enough egg whites for ½ the full recipe. Add salt and cream of tartar for ½ the full recipe. Beat the egg whites by method and amount found best under A, but leave them slightly underbeaten. Add the flour with number of strokes found best under B.

2. Beat the remainder of the egg whites from E1 the amount used in other experiments. Weigh out 38 grams and repeat E1.

3. Beat the remainder of the egg white from E2, until very dry and flaky. Weigh out 38 grams. Repeat E1.

When the sugar in the recipe is increased, should the egg white be beaten longer to coagulate a larger proportion, thus giving greater rigidity to hold the added sugar, or does overbeating lessen the rigidity of the egg white? What would be the effect of increasing the mixing of the sugar and the egg white? May the flour be increased to 107 grams when the sugar is increased to 1½ cups?

F. To determine the effect of reducing the proportion of flour in the standard recipe.

Reduce the flour for full recipe to 80 grams. Prepare ⅙ the recipe. Use meringue or standard method or both for beating eggs, beating an amount to give a desirable cake. Add flour as found best under B. If you think it advisable repeat the experiment, reducing the flour to 70 grams.

G. To determine the effect of different baking temperatures.

Prepare ½ the full recipe following directions under F and using amount of flour found most desirable. Divide the batter into 3 equal portions. Bake one cake at 160°C (320°F), the second at 175°C (357°F), and the third at 190°C (375°F).

H. To determine the effect of baking varying times.

1. Prepare ½ the full recipe. Divide into three cakes. Bake at 160°C (320°F) for 25, 30, and 35 minutes.

Sponge Cake

Experiment 47.

To determine the factors which influence the texture of sponge cakes.

Recipe:

Sugar	1 cup	200 grams
Pastry flour	1 cup	100 grams
Lemon juice	1 tablespoon	15 grams
Water	2 tablespoons	30 grams
Eggs	6	288 grams, yolks 108 grams, whites 180 grams
Lemon rind	1 tablespoon grated	
Salt	⅛ teaspoon	

A. Method of mixing.

1. Prepare ⅙ of the recipe. Bake at 160°C (320°F). Beat the egg yolk. Add the sugar, the lemon juice, the grated lemon rind, the water, and the salt. Beat until light, foamy, and lemon colored. Add the flour. Keep a record of the number of strokes used for mixing the flour. Beat the egg whites until they flow slowly when the bowl is partially inverted. Combine by folding the beaten whites into the egg and flour mixture. Keep a record of the number of strokes used for folding the egg whites in the flour mixture.

2. Beat the whole egg until light and foamy. Add the sugar gradually, then the lemon juice, lemon rind, water, and salt. Beat until light. Sift a portion of the flour over the top of the egg mixture and fold in. Continue until all the flour is used. Keep a record of the number of strokes used in folding the flour.

3. Add the lemon juice, lemon rind, water, and salt to the sugar. Stir until well mixed. Add the unbeaten egg yolk to the sugar and beat until light and lemon colored. Add the flour. Keep a record of the number of strokes used in mixing the flour. Beat the egg white until it flows slowly when the bowl is partially inverted. Add to the flour mixture, keeping a record of the number of strokes used for folding the egg whites.

4. Prepare ½ of the recipe. Make a sirup of ½ cup of sugar and ½ cup of water. Cook to 118°C and pour slowly over the beaten egg whites. Beat the egg white while adding the sirup. Cool. Beat the egg yolks, adding the lemon juice, lemon rind, and salt to the yolks. Fold the beaten yolks into the egg white. Keep a record of the amount of folding used for the egg yolks.

Sift a portion of the flour over the egg mixture. Fold in. Continue adding the flour until it is all folded into the egg mixture. Keep a record of the number of strokes used for folding the flour. Omit the 2 tablespoons of water in the recipe.

B. Variations in amount of mixing the flour and the egg white.

Repeat the series under A, but increase or decrease the number of strokes used in folding the flour and the sugar so as to obtain the best texture in the cake.

C. Vary the baking temperature.

CHAPTER
12

Starch, Flour, and Bread

STARCH

Uses. Starch, either alone or in flour, of which it may compose as much as 75% and averages 65–70%, is used in cookery: for thickening, as in soups and sauces; to form molded gels, *i.e.,* cornstarch puddings and similar desserts; and, because hydrated starch has adhesive qualities, as a cementing or binding material for holding pieces of food together in the sauce base of croquettes and in the framework of such baked products as muffins, biscuits, cakes, and breads. Hence its characteristics of special interest in food preparation are its gel-forming properties.

Sources of starch. Most of the starches and starchy foods used in food preparation are obtained from the cereals: rice, barley, rye, corn, and wheat. Starch is also obtained from tubers, potatoes and sweet potatoes being the principal sources. Arrowroot as well as some other starches are used to a limited extent. Tapioca obtained from cassava has been used extensively for industrial purposes as well as food.

Starch occurs in small particles known as granules. The granule size and shape are characteristic for each type of plant, so that an experienced person, by microscopic examination, can usually determine the source of the starch. The starch granule is insoluble in water at room temperature. No membrane surrounds the granules. Hence the contents of the swollen granule (26) are held together by hydrogen bonds between the branches of the amylopectin.

For descriptions of starch granules and photomicrographs, see articles by Butcher (9) and Scott (27). For photomicrographs, see Sjostrom (28), Woodruff (30, 32), Radley (18), and Sandstedt (23).

Some starch granules have a characteristic black spot called the hilum, which is an air space visible microscopically as a black spot. The hilum, even in varieties in which it is a definite characteristic, is not always present in all granules. In some starches distinct concentric markings or striations occur which are visible because certain portions of the granules contain less water and thus are denser than other portions. Naturally the size and to a certain extent the shape will vary with the growing conditions, so that sizes reported in the literature vary considerably.

Wheat granules are of two shapes and sizes. See Fig. 55. They are embedded in a more or less continuous matrix of gluten, a relatively larger number of the granules being free or not embedded in the gluten of soft-wheat than in hard-wheat flours. Larger granules average 25–35 microns in diameter and are oval and lenticular (bun shape, being flatter on one side). The small granules are circular and average about 3–5 microns. The hilum may show as a circular spot, and striations if present are faintly visible in large granules only.

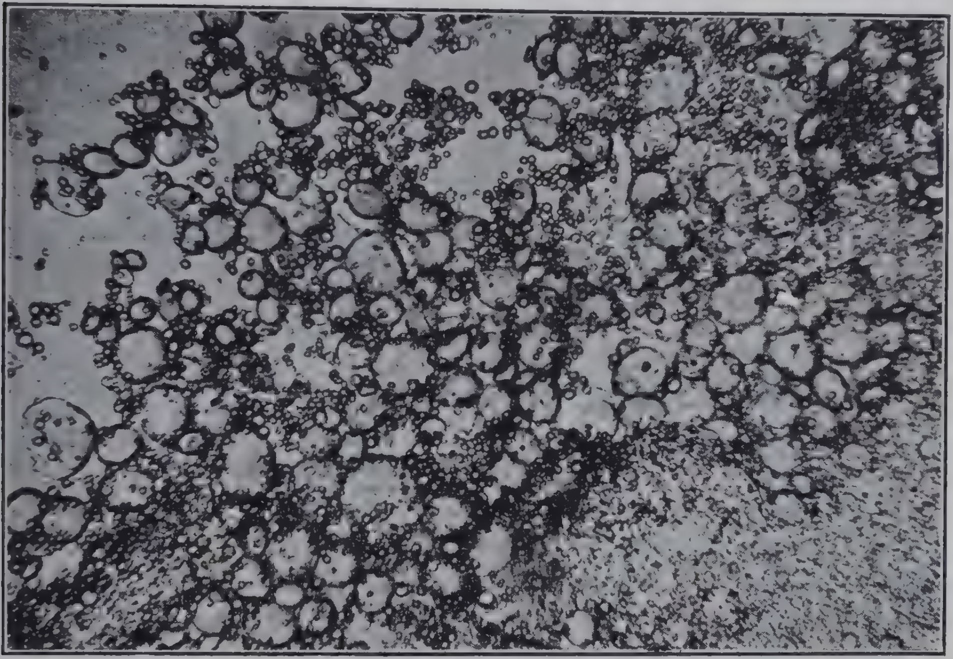
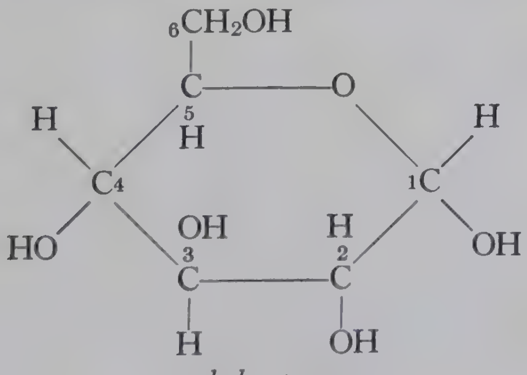


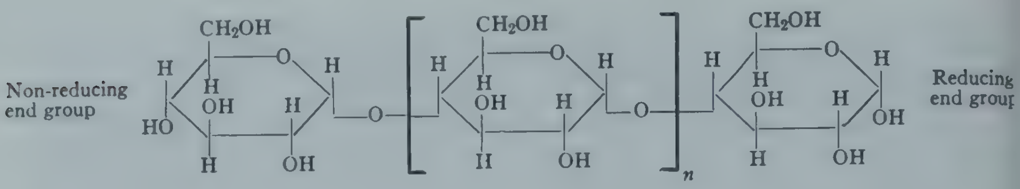
FIG. 55. A photomicrograph of flour with enough water so that it will stick to the slide. Note that the starch granules are both oval and round. Magnification approximately x 100.

The starch molecule. *The structure.* Starch is a polymer of glucose. On complete hydrolysis with acid, it yields 100% glucose. Haworth and coworkers (11) showed that starch is composed of repeating chain units of *α-d*-glucopyranose residues linked together through positions 1 and 4. See below.



α-d-glucopyranose

It has been shown that the polymeric linkage is a primary valency bond (6). Each starch molecule has a reducing or aldehydic group at one end and a non-reducing group at the other end.



X-ray patterns. Powdered natural starch gives fairly good x-ray patterns (4, 7). The x-ray patterns indicate that starch, a colloidal amorphous substance, is made up of a single crystalline component.

Composition. A debate had continued for years as to whether starch is composed of one or two carbohydrate substances. Schoch (26) states that three major difficulties prevented the settlement of this issue: "(*a*) the lack of any clean-cut method for separating the various components of starch, (*b*) the absence of any exact chemical criteria by which to differentiate these fractions, and (*c*) the absence of any fundamental theory to explain the structure and behavior of high polymers." Great progress has been made along these lines. Starch is composed of two components, amylose and amylopectin. Various names have been given these components. Most starches are composed of varying proportions of amylose and amylopectin. The amount reported in different starches appears to vary with the method of determination. Using the iodine titration method, the Iowa investigators (5) found that the amount of amylose in starches from various sources varies from 17 to 34%.

In addition to starch granules from different sources being characterized by different shapes and sizes, they also behave differently when made into pastes. Part of this variation in behavior can be attributed to the composition or relative proportions of amylose and amylopectin. However, some starches (13) such as corn, wheat, and potato have about the same proportion of amylose, 21–24%, but behave differently in pastes. Hixon suggests that part of this difference can be attributed to variations within the fractions. For example, the chain molecules from potato starch average 2 times as long as those from cornstarch.

Some cereal starches contain no amylose. They are found in some strains of maize, rice, rye, barley, and some other cereals, but there are none in wheat. They are called waxy starches.

Phosphorus-containing compounds, fatty acids, and some nitrogenous matter are also found in starch granules. It is interesting to note that waxy maize starch (17), containing essentially pure amylopectin, contains about 1/7 as much "fat-by-hydrolysis" as ordinary starch.

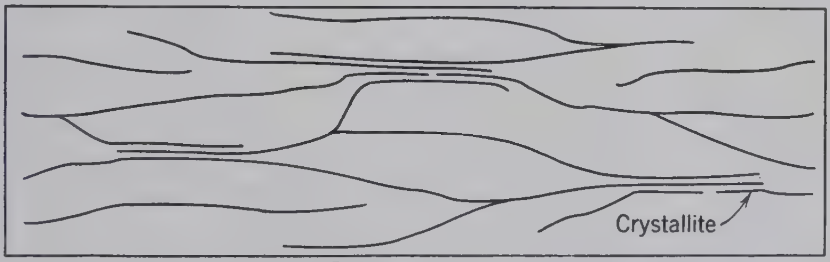
Amylose. Amylose has a long chain-like configuration. Meyer and coworkers (16) have shown that the number of reducing ends of amylose equals the number of non-reducing ends and that it is broken down completely to maltose by β-amylose. Thus it is a straight chain. The number of units of glucose in the amylose chain is given as 100–700 (16) and as 200–300 (25). Amylose (16) is partially soluble in hot water, the solubility increasing with rise of temperature and decreasing with increased granule size. With increasing purity it becomes less soluble.

Mikus et al. (17) state that amylose with a helical chain configuration will bind iodine and fatty acid, whereas with an extended configuration it will not bind fatty acids. They give evidence to show the similarity of fatty acid and iodine complexes with amylose. The fatty acid or the iodine molecules occupy a hole in the center of the helices.

Schoch (25) states that, in a colloidal sense, amylose is unstable and accounts for the retrogradation of starch. It is selectively precipitated by butanol.

Amylopectin is the component of greater value in many industrial uses, but for culinary purposes some amylose is desirable. Amylopectin gives a viscous, translucent paste but is thin and runny when cooled. On the other hand, amylose is more opaque and sets to a firm gel when cooled after cooking.

Amylopectin. Amylopectin possesses a single aldehydic terminal or reducing group, but many non-aldehydic groups. Its configuration is given as a very large branched molecule, tree-like, with the non-reducing groups at the open ends of the branches. See Fig. 56. The branches are united to the chain through carbon 6. Meyer (16) suggests that the outside branches are composed of 15–18 glucose units, the interior branches of 8–9 units. Schoch (26) suggests that branching occurs at about every twenty-fifth glucose unit and the molecle is composed of 500 to more than 2000 glucose residues. It does not form a complex with fatty acids.



Courtesy Dr. R. M. Hixon and Baker's Digest

FIG. 56. Schematic diagram of arrangement of molecules in starch to form crystallite areas.

Amylopectin gives a reddish color with iodine. Hixon and Sprague (12) state that amylopectin pastes have high viscosity, but low gelling characteristics, with slight tendency to retrograde. β-amylose breaks down about 40–50% of amylopectin to maltose.

Swelling of starch. Radley (19) defines true swelling of starch as reversible. This occurs in cold water and is slight. No gel structure is formed. Alsberg (1) states that the axes of the starch granule may increase as much as 15%. No change in the starch structure is observed microscopically, and the granules do not lose their birefrengence. Starch may be treated so that it swells enormously and forms a paste in cold water. Starch is hygroscopic, absorbing and losing moisture readily with variations in the humidity of its surroundings.

The heat of hydration (the amount of heat evolved when a substance takes up water) of flour (29) decreases with increased moisture content but not linearly. It is the same for large and small granules of wheat and potato starches (29) but varies with different starches, increasing in the order named: rice, wheat, potato.

Gelatinization. When starch granules are heated in water they swell enormously, increase in viscosity, and become translucent. They become more soluble or lose starch from the granule to the solvent, lose their power of anistropy (unequal refracting power), and they can no longer be obtained in their original form. This is gelatinization.

Temperature. Gelatinization (1) is gradual over a range of temperature often as great as 50°C. If starch granules (22) are soaked for some time before heating, the gelatinization begins at a lower temperature. Not only is the temperature at which swelling begins variable for the particular sample being used but also the range in temperature over which swelling occurs and the type of gel formed are characteristic for each kind of starch. Potato and tapioca (10) are practically identical in gelation range, which begins around 65°C. Corn and sago gelatinize approximately together (10, 20) at a temperature range about 5.5°C higher than that of potato and tapioca. However, wheat starch (10) commences to gelatinize at about the same temperature as potato, but the swelling process is slow and occurs over a wide range of temperature, not reaching its maximum until a temperature of 85°C (185°F) is reached. Cornstarch (20) has also been reported to gelatinize over a wide range of temperature.

According to Radley (18), if soap is added to the starch the gelatinization temperature is elevated, and sufficient soap prevents gelatinization.

Woodruff and Nicoli (31) heated 5% starch suspensions by weight in a water bath at such a rate that 38 minutes was required for the paste to reach 90° and 22 minutes longer to reach 99.5°C. They found that the translucency increased suddenly at a temperature specific for each starch, this temperature not being sharp but covering a range of 1–2°. Heating a longer time to a higher temperature did not increase the translucency. These temperatures follow: corn, 86–87°; wheat, 87–88°; rice, 84–85°; potato, 60–70°; arrowroot, 79–80°; and cassava, 74–75°C. It was necessary to heat each starch to 90° or higher for maximum gelatinization.

The salt content. Swelling (19, 21) is greater in distilled water than in salt solutions. Some salts may lower the gelatinization temperature to such an extent that the swelling process can be studied at room temperature. The following in the percentage concentrations stated (19) can be used: NaOH, 0.53; KOH, 0.75; KCNS, 12–15; KI, 26–28; NH_4NO_3, 30–35; $AgNO_3$, 29; and chloral hydrate, 55. In general the swelling (15) increases with increase in concentration of the salt used. The anions form a lyotropic series in the following order: Cl < Br < CSN < salicylate < OH.

The size of the starch granule. Alsberg (2) states that Nageli found that large granules of potato starch begin to gelatinize at 55°C, whereas the smallest granules do not start to gelatinize until a temperature of 65°C is reached. As observed by a hot-stage microscope, Caesar (10) says that gelatinization "is distinctly progressive, the larger granules being first to swell, followed by an almost simultaneous 'popping' of the mass, and ending grudgingly with swelling of the smallest and most resistant units." The swelling of the larger granules (1) first is explained on the basis that they develop a greater internal pressure per unit of granule surface with hydration than the smaller granules. The large granules swelling and absorbing more water earlier than small ones may affect the plasticity of the dough. If (2) "the average granule size is small, this effect would come later than if the average size is large." In general, the longer a dough remains plastic, other things beign equal, the greater is the volume of the baked loaf.

Concentration of the starch. In 50% concentrations (32), heating to 95°C causes no greater swelling than does a temperature of 65–70°C in a 5% suspension, although the 50% concentration becomes moldable at 53–55°C.

Stiffness of starch gels. The stiffness of starch gels varies with (*a*) the concentration of the starch, (*b*) the different starches, (*c*) the temperature to which the starch is heated, (*d*) the fat content, (*e*) the size of the starch molecule, (*f*) the proportion of amylopectin, (*g*) the extent of shaking or stirring during gelatinization, and (*h*) factors that reduce the size of the starch molecule such as (i) acid, (ii) enzyme hydrolysis, and (iii) dry heat. Gelatinization and viscosity are closely related, the swelling during gelatinization increasing the size of the granule and thus the viscosity of the paste. Viscosity is usually determined on the warm or hot pastes, stiffness on the cooled gel. Some of these factors have been discussed.

Concentration of starch. Brimhall and Hixon (8) determined the rigidity of the resulting gels when different concentrations of corn, tapioca, and waxy maize were heated at various temperatures. They found that the rigidity curves for various concentrations of commercial cornstarch pastes heated at 90°, 80°, and 70°C were very similar. The stiffness of the paste changed very slowly as the amount of the starch was increased until a critical concentration was reached, above which the rigidity increased enormously for a slight increase in the concentration of the starch. For example, the stiffness of the paste heated at 90° changed very little with 3–5% of starch, but increased rapidly with concentrations of 5–6%. When starch was heated at 80° the concentration had to be 6–8% and at 70° 9–10% to be the same stiffness as the starch heated at 90°.

Different starches. It has long been known in food preparation that starches from different sources need to be used in varying concentrations if the gel to be served is stiffened to the same extent.

Woodruff and Nicoli (31) determined the stiffness of starch gels of 5% concentration. The results, arranged in order of decreasing stiffness, are: corn, wheat, rice, potato, arrowroot, and cassava. Other differences were noted: of the three cereal starches, rice was the most translucent and tender when cut; corn was the firmest, the cold gel being chalky white; and wheat was intermediate between these two. For the other starches, the potato paste was ropy and too gummy to leave the mold well so that it gave a poorly formed gel, although quite transparent; arrowroot gave a still softer and more transparent gel; and cassava starch gave only a viscous fluid. It was necessary to heat the gel to 90°C or higher for maximum stiffening, but heating of any one starch to 90°, 95°, 99.5°C gave gels indistinguishable from one another.

Temperature to which the starch is heated. Although starch may swell to a certain extent at lower temperatures, it does not reach its maximum viscosity until a higher temperature is reached. However, the temperature for maximum viscosity varies somewhat with the sample of starch. For example, in one series of tests (3) the maximum viscosity of wheat starch occurs at 95°C, of corn at 91°C, but in other tests (20) the maximum viscosity of cornstarch does not occur until a temperature of 100°C is reached. Woodruff and Webber (32) find that a 5% starch gel must be heated to at least 90°C before a moldable pudding is obtained. Furthermore, rapid heating to this temperature gives better-formed gels than slow heating. The firmest gels of this series were obtained by heating to 95°C or above.

One interesting result of the tests of Brimhall and Hixon (8) was that for each starch used, when heated above a certain temperature, the stiffness of the paste decreased. For cornstarch, this temperature was above 90°. Cornstarch pastes autoclaved at 120°C gave scarcely any rigidity. For tapioca this change occurred above 70°. Some change occurred in the starch granules at these temperatures which caused the downward trend in the rigidity-temperature curves. A 6% cornstarch paste reached its maximum stiffness about 95°C, a 7% tapioca one at 65°, and a waxy maize one at around 70°.

Caesar (10) also found that the stiffness of starch gels is reduced by heating to a temperature beyond that at which maximum swelling occurred. He states this temperature is higher for wheat than for corn, tapioca, sago, or potato starch.

Phosphorus content. Meyer (16) states that the phosphorus content of the starch does not affect its paste-forming properties as was formerly thought.

Fat content. Schoch (26) states that defatting the starch renders its pastes less opaque, more readily dispersed, and increases the gel strength.

Acid. It has been shown (14, 20) that there is a relationship between the molecular weight and viscosity of the starch solutions and that grinding reduces the molecular weight. Acid causes hydrolysis of the starch molecule, thus reducing its size, although it is not known whether the hydrolysis occurs at the glucosidic or the lateral linkages or at both. In their earlier work, Richardson et al. (20) suggest that the attack occurs at random along the starch chains, so that in any gel of acid-modified starch there is a wide distribution of chains of varying length. As hydrolysis proceeds and an increasing number of shorter chains is produced, the stiffening power is reduced. Hydrolysis with acid is more rapid (*a*) as the temperature is increased, (*b*) as the time the paste is held at the higher temperature is increased, and (*c*) as the concentration of the acid is increased. In lemon pie filling the lemon juice is usually added after the starch, water, and sugar have been boiled.

Enzyme hydrolysis. Hydrolysis is brought about by diastatic enzymes.

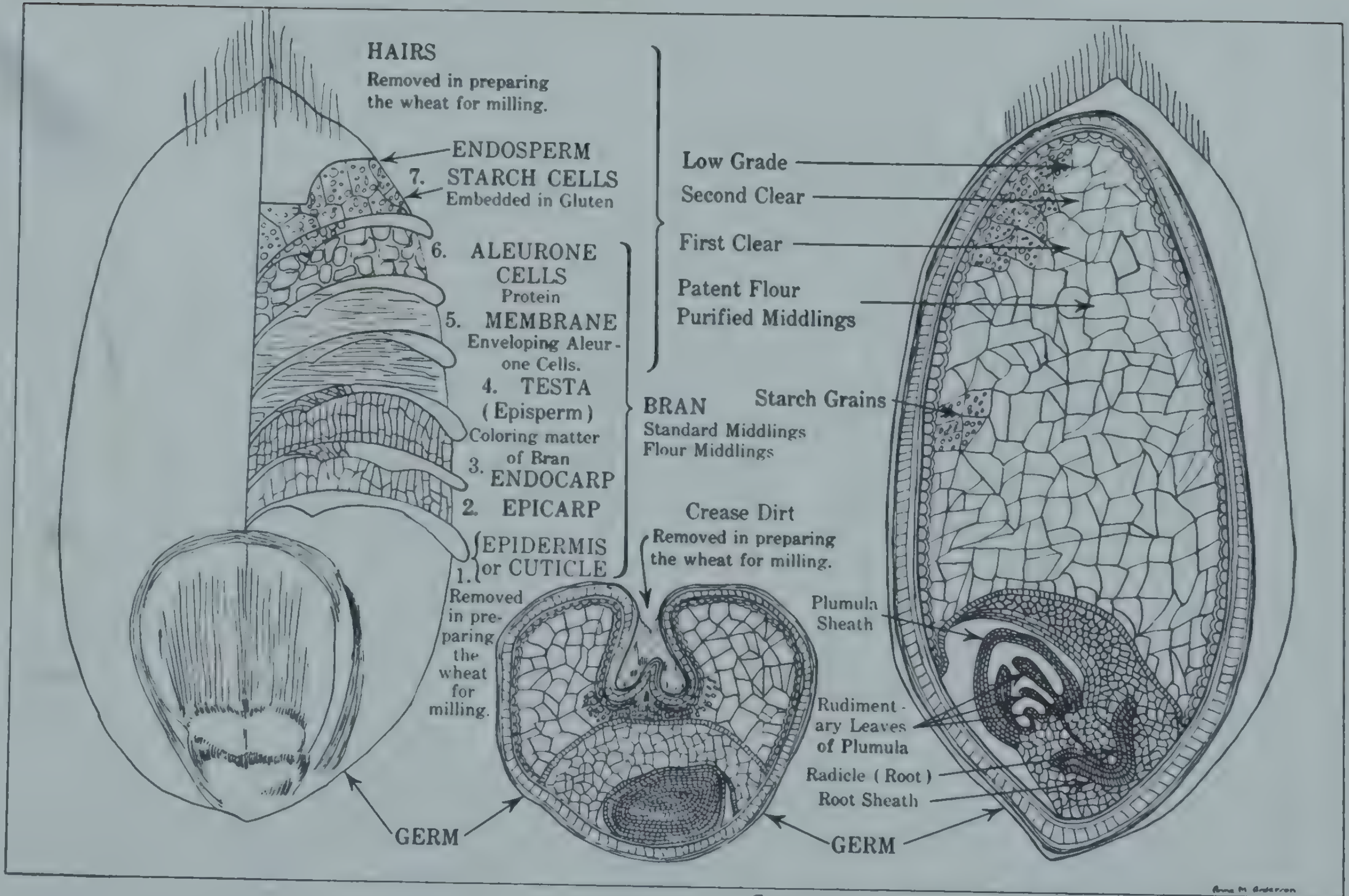
Heat. The molecular weight or chain length may be reduced by browning the starch (*a*) by dry heat, *i.e.,* in air or in fat, and (*b*) on the surface of baked products such as bread. A larger amount of "browned starch or flour" than of the unbrowned product is required for thickening gravies.

Sugar. Starch gels (31) made from 5 grams of corn, wheat, rice, potato, arrowroot, or cassava starch and 95 grams of water require heating to 90°C or higher before the cooled gels are strong enough to retain the shape of a mold. When 10, 30, 50, or 60 grams of sucrose are added to the above quantities, the three root starches form increasingly softer gels with increasing sugar concentration, the 50 and 60 grams producing a sirup instead of a gel. Although the three cereal starches show increasing transparency and tenderness with increase of sugar, a gel that will not mold is not obtained until more than 50 grams of sucrose are added. A sirup is obtained with 60 grams of sugar and the cereal starches.

FLOUR

The composition of wheat may vary with several factors, such as varying rainfall, temperature, and other climatic conditions, irrigation, texture and composition of the soil, and the use of fertilizers. Bailey (40) reviews all these factors and others in *The Chemistry of Wheat Flour.* Also see *Modern Cereal Chemistry,* by Kent-Jones and Amos (87).

The kind of flour and to a great degree its composition depend upon (*a*) the milling process, (*b*) the classes of wheat from which the flour is milled, and (*c*) the purpose for which the flour is intended. Flour is also



Courtesy of International Milling Company, Minneapolis

FIG. 57. The structure of a wheat kernel. The bran layers are shown peeled back from the kernel. The portion from which the different flours are obtained is shown in the longitudinal section.

made from bananas, barley, buckwheat, corn, cottonseed, lima beans, peanuts, potatoes, rice, rye, soybeans, and sweet potatoes, but the term flour refers to wheat flour when no grain or product is mentioned.

The milling process and the structure of wheat. The wheat kernel may be divided into three main parts: the bran, the germ, and the endosperm, the relative proportion of each part of the entire kernel being respectively about 14.5, 1.5, and 84%. Milling is the process of separation of the endosperm from the bran and germ. When no separation is made, or all the flour streams are reunited, the flour is known as whole-wheat flour, but otherwise the completeness of separation determines the resulting grade of flour. If the separation is so complete that only the heart of the endosperm is used, the resulting flour may be called a fancy or short patent. The 72–75% usually obtained from the endosperm is called straight flour. The remainder of the wheat kernel constitutes the bran and shorts. Between the two extremes of flour, whole wheat and fancy patent, are many other kinds.

The steps in the milling process may include the following: cleaning, tempering, breaking, sifting, or separating the primary products, purifying, reducing, bolting, flour blending, and bleaching.

The structure of the wheat berry is shown in Fig. 57. Layer 1, sometimes called the bee's wings by millers, the hairs, and the dirt on the berry, particularly that in the crease, are removed in the cleaning operations preparatory to milling. Layers 2 to 6, shown in the surface drawing and the longitudinal and cross sections, constitute the bran coats.

The gross appearance of a cross section of a wheat berry varies somewhat with the type of wheat and the ripening conditions. Hard wheats are more flinty and vitreous than soft wheats. The amount of gluten as well as the type is different in hard and soft wheats. The gluten forms a continuous matrix in which the starch granules are embedded. When the grain contains a large proportion of gluten, the starch granules, as they dry out in ripening, are more firmly cemented to or held in the gluten matrix.

Microscopic observations of wheat and flour (71) show that during milling the soft-wheat cells break up indiscriminately, but in hard wheats the fractures tend to occur between the cells.

Tempering is a preliminary step to milling and consists of adding a definite amount of water at a certain temperature to wheat berries, the amount depending on the moisture content of the wheat and other factors such as relative plumpness and hardness of the kernels. In tempering wheat the water is usually not left in contact with the wheat long enough for moisture to be absorbed by the endosperm. Thus the pliableness and toughness of the bran coats are increased so that they are more easily separated from the endosperm. Sometimes, to prevent the endosperm from breaking into very fine particles, the water is added in two portions, part of the first addition being absorbed by the endosperm.

The germ because of its high fat content is easily flattened or flaked and is removed by bolting from the other constituents of the wheat berry during milling. The endosperm constitutes about 80% of the wheat berry. The starch is more concentrated in the immediate vicinity of the germ and in the interior of the endosperm. The concentration becomes less and less towards the outer layers of the wheat berry. The starchy endosperm being drier and more friable tends to shatter more readily when the berries are fractured or broken between rollers.

In the first breaks, the wheat kernels are mostly broken into large fragments by the corrugated rollers. The coarser fragments, which are separated from the finer ones by sifting, are returned to the next set of break rolls, of which there are five or six. Other things being equal, a larger proportion of fine particles is obtained from soft wheat than from hard wheat during the first breaks.

Bolting or sifting, which occurs after each break, is the separation of the coarse particles, which are reground, fine granules of flour, which are not reground, and intermediate particles, which are sent to the purifier.

Purifying refers to a part of the milling process whereby particles pass over a sloping, vibrating sieve. At the entrance the meshes of the sieve are fine but gradually increase in size to the discharge end. As the particles travel down this sieve they are separated according to size. During this process controlled air currents lift out the flakier and more fibrous particles. The remainder of the particles, known as purified middlings because they are freer of branny, fibrous material, yield a more highly refined flour after reduction.

The purified middlings are ground between smooth steel rollers to reduce them to the desired fineness. Since the flour bolted from the first grinding of any stream of purified middlings is more highly refined, because it is freer of fiber than that produced by subsequent grinding of the coarser residues, it is often used in making the so-called short patent flours.

The separation of the endosperm from the bran coat and germ is never 100% complete, some small bran particles being found in the flour, and vice versa. The wheat berry may be separated into the following portions, the percentage of bran particles progressively increasing with each portion named: patent, straight, first clear, second clear, red dog, flour middlings, shorts, and bran. The desirability of each portion for making white bread and biscuits decreases with increasing bran content.

Flour terminology. According to the committee on terminology of the Millers' National Federation, in cooperation with the U. S. Department of Agriculture, grade refers to the type of flour as determined by the milling process, whereas class designates the kind of wheat from which the flour is milled.

Classes of wheats used for flour. Wheats are classified in five main groups as follows: (*a*) white, (*b*) hard red spring, (*c*) hard red winter, (*d*) soft red winter, and (*e*) durum. Since the composition of the wheat varies with climatic and soil conditions to which it has been subjected in growing, it is natural that many variations in composition occur within each class. The sections in which the different classes of wheat are grown overlap. The major portion of the hard red spring wheat and durum wheat is grown in the North Central States of the United States and in Canada; hard red winter wheat is grown chiefly in the South Central and Middle Central States. This class of wheat leads all others grown in Iowa, Nebraska, Kansas, Oklahoma, Texas, and Colorado. At present twice as much acreage is planted in hard red winter wheat as in any other class of wheat. Soft red winter wheat is grown in Missouri and the eastern half of the United States. It is also grown in some western states, particularly Oregon, Washington, and Idaho. White wheat is grown to a limited extent in the northeastern part of the United States and in Michigan, New York, and on the Pacific Coast.

Definition of flour. The definitions of flour and cornmeal are published in the 1949 edition *Code of Federal Regulations,* Title 21, sections 15.00–15.514 (64*a*). Also see the Federal Register (64*c*). Definitions are given for flour, enriched flour, bromated and enriched bromated, durum, self-rising and enriched self-rising, phosphated, and whole-wheat flours.

Flour. "§ 15.000. . . . Flour, white flour, wheat flour, plain flour is the food prepared by grinding and bolting cleaned wheat other than durum wheat and red durum wheat; to compensate for any natural deficiency of enzymes, malted wheat, malted wheat flour, malted barley flour, or any combination of two or more of these, may be used; but the quantity of malted barley flour so used is not more than 0.25 per cent. . . . The flour is freed from bran coat, or bran coat and germ, to such an extent that the per cent of ash therein, calculated to a moisture-free basis, is not more than the sum of one-twentieth of the per cent of protein therein, calculated to a moisture-free basis, and 0.35. Its moisture content is not more than 15 per cent. . . ."

Enriched flour conforms to the definition and standard of identity and is subject to the requirements for label statement of optional ingredients, prescribed for flour in § 15.00, except that it contains for each pound of flour between the minimum and maximum amounts of the ingredients as

REQUIRED INGREDIENTS	MINIMUM	MAXIMUM
Thiamine	2.0 mg	2.5 mg
Riboflavin	1.2 "	1.5 "
Niacin	16.0 "	20.0 "
Iron	13.0 "	16.5 "
OPTIONAL INGREDIENTS		
Calcium	500.0 "	625.0 "
Vitamin D	250.0 U.S.P. units	

tabulated. Enriched flour may also contain not more than 5% by weight of wheat germ or defatted wheat germ.

The ingredients for enriched self-rising flour are the same as for enriched flour except that calcium is required instead of optional.

Bromated flour. $KBrO_3$ is added in a quantity not exceeding 50 parts to each million parts of the finished flour; it is added only to flours whose baking qualities are improved by such addition.

Phosphated flour has calcium phosphate added in a quantity not less than 0.25% and not more than 0.75% of the weight of the finished phosphated flour.

Whole-wheat flour, graham flour, entire-wheat flour, is flour containing the unaltered natural constituents, with the exception of moisture, in the same proportions as in the wheat from which it is made.

Straight flour (100% flour) is a milling term indicating all the flour from the wheat kernel after removal of the bran coats and germ before its division into grades. Straight flour will make acceptable white bread and biscuit but is not generally on the market.

Patent flour may be made from any class of wheat and comes from the more-refined portion of the endosperm. How "long" or "short" a patent is depends on how much of the total or straight flour is included. In general most patent flours include about 85% of the straight flour. But a very "short" patent used in fancy cake flour may include only 25% of the endosperm.

Clear flour is the less-refined bolted portion of the wheat meal recovered in the manufacture of patent flour. According to trade practice or demand, clear flour may be divided into first and/or second clears.

Self-rising flour is prepared by mixing salt and a leavening agent with the flour. The leavening agent usually consists of $NaHCO_3$ and $CaH_4(PO_4)_2$ in such proportions and quantity that the $NaHCO_3$ is neutralized and 0.5% CO_2 is evolved.

Blended flour. Flours may be blended to definite specifications. An example is blending of hard- or soft-wheat flours for pretzels, which require a fairly high protein content to stand up under lye dipping. Sometimes the blend is from hard- or soft-wheat flours only, sometimes a combination of these two classes.

Hard-wheat flours. Practically all durum wheat is used for the manufacture of semolina, which in turn is used for macaroni products.

In general bread flours are made from hard wheats, although suitable soft-wheat flour is used for baking bread in some sections. Bread flour is a term indicating a "strong" flour that has the capacity to make loaves of good volume, texture, and grain. The term "strong" indicates that the gluten has tenacity, cohesiveness, and elasticity. Bread flour usually contains more gluten and less starch, and the granulation is usually coarser than in either pastry or cake flour.

All-purpose, general-purpose, or family flour are synonymous terms for a flour which is suitable for most kinds of baking. It may or may not be a blended flour. It may have as a basis either hard- or soft-wheat flour, or a combination of these. Hence, there are two types of all-purpose flours, the hard-wheat and the soft-wheat. The kind obtainable in a certain section depends on whether hard or soft wheat predominates there. There is a trend for all-purpose flours to have less protein than formerly, since most all-purpose flours are now being designed to make yeast-leavened breads with the shortest possible rising periods.

Soft-wheat flours. Since soft wheats usually contain a smaller quantity of gluten than hard wheats, the flours from these wheats are generally more desirable, particularly if the gluten is of fine quality, for cakes and pastry products than hard-wheat flours.

Pastry flour is a term indicating a flour usually milled from soft wheat, which is of fine granulation and has a low or moderate amount of gluten. It differs in baking quality from both bread and cake flours.

Cake flour is milled from soft wheat. It is a "short" patent. The granulation is very fine and uniform; the protein content is low but may be of fine quality. Cake flours are usually better grades of flour than pastry flours.

Cracker flour is milled from soft winter wheat. A desirable cracker flour (96) differs from bread flour in color, absorption, and fermentation capacities. Because of the long fermentation period the inside color of crackers is quite uniform but the color of the flour affects the outside color and bloom of the cracker. A cracker flour has a lower water-absorbing capacity than bread flour, and, since little sugar is added, the flour must itself furnish the necessary fermentative material.

The geographical areas in which the different classes of wheat are grown determine to a great extent the type of flour that predominates in local retail markets in these areas. For example, in Iowa it is very difficult to obtain soft-wheat flour, except in the specially prepared cake flours, the bread and all-purpose hard-wheat flours being found on the local markets. In Alabama it is just as difficult to obtain hard-wheat flours. In some sections or states both soft- and hard-wheat flours are readily obtainable.

Bleaching and maturing flour. Flour when first milled has a slightly yellow color. In addition, freshly milled wheat flour does not bake as good a loaf of bread as a matured flour. Natural aging will bleach and mature the flour without the use of chemicals, but this requires several weeks for most flours, which means that storage facilities must be provided. Chemicals can be used to bring about these changes quickly. In chemical bleaching (74) an oxidizing substance is used to increase the whiteness of the flour; maturing is improving the baking quality. Nitrogen trichloride (74) was introduced into the United States in 1921. Its use increased until the major portion of the treated flour was matured with it. Mellanby (95) reported in 1946 that dogs fed bread (if the flour used therein had been treated with nitrogen trichloride) developed canine hysteria or running fits. After Mellanby's tests were corroborated in the United States, the use of nitrogen trichloride was discontinued August 1, 1949. Chlorine dioxide has largely taken its place.

The Food and Drug Administration (64*a*) permits the use of one or any combination of the following chemicals, but regardless of their action classifies them as bleaching agents: (*a*) oxides of nitrogen, (*b*) chlorine, (*c*) nitrosyl chloride, (*d*) chlorine dioxide, and (*e*) 1 part by weight of benzoyl peroxide with not more than 6 parts by weight of several substances, named in § 15.00 (64*a*). Oxides of nitrogen and benzoyl peroxide bleach the flour and have little maturing effect. Only a small number of mills use oxides of nitrogen (mainly nitrogen peroxides). Nitrosyl chloride is not used alone. Chlorine or chlorine with an admixture of nitrosyl benzoyl bleach and mature the flour. They are used largely for improving the quality of cake flour. Chlorine-treated cake flours are said to be less likely to fall, will carry a higher percentage of shortening and sugar, thus producing sweeter and tenderer cakes (74). Chemicals for bleaching or maturing are optional ingredients, and flour in which they are used must be labeled "Bleached."

The principal maturing chemicals are: chlorine, chlorine dioxide, and potassium bromate (118). Potassium bromate has no bleaching action. Sullivan states that $KBrO_3$ maintains greater uniformity of baking characteristics than chlorine or chlorine dioxide, and it reacts only when the flour is made into dough. Millers and bakers regard the maturing of flour as more important than bleaching.

Rye Flour

Bailey (42) has reported formulas and methods for testing the use of rye flour in bread. There are five classes of rye flour, based largely on the color: white, light, medium, dark, and extra dark.

Composition of Flour

Flour contains vitamins, pigments, enzymes, cellulose, moisture, fat, ash, carbohydrates, and proteins. Most of these constituents affect the baking qualities of the flour.

Vitamins

Whole cereals are, in general, considered a good source of the B vitamins.

Thiamine. Thiamine (78) added in concentrations up to 12 mg per kg of flour had no influence on the elastic properties of the dough. The loss of thiamine in baking bread has been reported as small (97) and to vary from 5 to 9% (80). Loss in toasting (80) varied from 0 to 17%.

Zaehringer et al. (157) have reported that thiamine retention in yeast bread and rolls decreased as the products were baked to a darker crust color. Thiamine retention was greater in rolls than in bread. The greater loss in bread than in rolls was attributed to the longer exposure to heat or longer baking time for bread. Within the rolls, thiamine retention was greatest in the products having the smallest surface areas and the thinnest crust.

Barackman (51) states that, if biscuits made from self-rising flour are baked under optimum conditions, about 85% of the added thiamine survives the baking process. However, the *p*H of the baked product must be 7.1 or lower. Barackman suggests adding 0.25% additional calcium acid phosphate to enriched self-rising flour. This would tend to lower the *p*H. It is predicted that the use of phosphate-enriched flour instead of plain flour will increase thiamine retention in biscuits made with baking powder, for most baking powders increase the alkalinity of the dough above *p*H 7.0. Baking conditions and methods of dough preparation have no appreciable effect on thiamine loss provided that a thin, crusty biscuit is not made. Biscuits made with milk show less loss of thiamine than those made with water. Skovolt and Bailey (115) have shown that increase of milk solids in dough reduces the *p*H.

The thiamine values (111) of 31 samples of commercial breads made from whole-wheat flours varied from 1.92 to 2.53, averaging 2.27 mg per lb of thiamine.

Riboflavin. No measurable loss of riboflavin occurs in baking bread, but large losses occur when slices are exposed to light. These losses are greater in white than in whole-wheat bread. In one instance, when a 40% loss occurred in white, there was only 10% in whole-wheat bread.

Color of Flour

Bailey (40) gives five factors affecting the color of flour: (*a*) Granulation or size of flour particles, which affects the appearance of the flour and not that of the dough. Large granules appear darker than small ones. (*b*) Color changes occurring when flour is mixed with water in contact with air at elevated temperatures are caused by enzymes found principally in the bran. (*c*) Dirt and foreign matter, as weed seeds, if highly pigmented, may become pulverized and color flour. (*d*) A reddish brown pigment is present in small quantities in flour made from "red" wheats. Highly refined flours from these wheats show less of these small bran particles. (*e*) The pigments of the flour.

Flour pigments. The principal carotenoid pigment (41, 127) is a xanthophyll of the lutein type (not a provitamin A) with a small proportion of carotene.

The flavones are water-soluble pigments. Flavones (92) have long been known to exist as glucosides, and it seems they may be found as esters of the fatty acids. The flavones are colorless in acid or neutral mediums but develop a greenish yellow tint in alkaline reactions.

Enzymes

Of the enzymes of flour and wheat, the diastases or amylases and the proteinases are the most important from the standpoint of baking, particularly during the fermentation of cracker and bread doughs.

Diastases. The diastases convert starch to sugar, which in turn is converted by the yeast to CO_2 and other fermentation products. Variation of the diastase content of flour (90, 91) is caused chiefly by environmental factors. According to Andrews and Bailey (38) the diastatic activity of sound normal wheat and flour is due primarily to the action of β-amylase. However, when wheat germinates, a second "diastatic factor," called α-amylase, is produced. Both convert starch to reducing sugars, the α-maltase yielding α-maltose, the β-amylase producing the corresponding β-sugar. The maximum activity of β-amylase occurs at *p*H 4.5–5.1; that of α-amylase, at *p*H 5.6 to 5.8.

Blish, Sandstedt, and Kneen (57) have found that β-amylase acts on starch that has been rendered available (soluble) by physical, chemical, or biological means, but does not act on the intact raw starch granules. The amount of soluble starch can be increased by fine grinding of the flour, or by the addition of a raw starch biocatalyst, which occurs most abundantly in malt. Jones (83) emphasizes that no appreciable diastatic action would occur if there were no injured starch granules and gives photomicrographs of such granules. The action of β-amylase (57) ceases when approximately 60% of the soluble starch has been saccharified; the greater the concentration of β-amylase the more rapid is the conversion. The addition of malt to flour furnishes a catalyst which acts on raw starch and in addition an α-amylase which permits the saccharification of the soluble starch to proceed beyond the 60% level brought about by the β-amylase. The reaction of α-amylase is not proportional to its concentration, its activity slowing down with time.

Proteinases. Jørgensen (84, 85) and others (48, 49) have reported that flour contains powerful proteolytic enzymes of the papain type, which are usually latent but may be activated by cysteine, glutathione, and possibly other products. Excess proteinase or proteinase activators (65, 106) can ruin the baking properties of a gluten by reducing a stiff dough to the consistency of a thick soup. Some flours have proteins that produce inelastic, rather firm glutens which yield the so-called bucky doughs. These flours may be improved by adding suitable amounts of proteinases or proteinase activators.

Cellulose

The greater part of the cellulose of the wheat kernel is removed in milling, so that the amount in white flour is small.

Bran. Bran contains considerable cellulose, which absorbs water slowly. Rahn (105) describes a process for treating bran which increases its digestibility, keeping quality, and water-absorbing powers.

Moisture

By the United States standards the moisture content of flour should not exceed 15%. From different reports 11–13% of moisture seems to be a normal content of flour over a large section of the United States.

Bailey (40) states that flour responds more readily to changes in humidity than the wheat kernel, because of its fineness of division of particles and the greater exposure of handling it in sacks.

Hygroscopic property of flour. The starch of flour takes up and releases moisture quickly. Browne (60) in determining the hygroscopic moisture of carbohydrates found that anhydrous starch ranked first in the amount of moisture absorbed at 60% humidity in 1 hour. Over longer periods the starch did not absorb as much moisture as some of the sugars. Kent-Jones (87) states that English flour has a moisture content 0.5–1% higher than American flour owing to the higher humidity of the English climate.

The Lipids of Flour

The percentage of fat in white flour is low, since most of the fat is found in the germ which is removed during milling. Sullivan (117) reports that the wheat contains 3.0% of lipids, whereas the percentage distribution in the various separations is as follows: short patent, 1.3; straight, 1.6; clear, 2.7; low grade, 3.2; bran, 6.5; shorts, 7.5; and germ, 15.5. The fat extracted from the germ (117) contains 16% of saturated fatty acids, chiefly palmitic, whereas linolic acid composes over 52% of the unsaturated fatty-acid fraction. Of flour fat (117) the major portion of the saturated fatty acids is also palmitic, and of the unsaturated, linolic. However, flour fat contains a higher percentage of the volatile fatty acids and of unsaponifiable material than the germ. The iodine number (121) of the total fatty acids of petroleum-ether extract of flour is 125; that of the unsaturated acids, 146.

Barton-Wright (53) obtains practically the same composition of saturated and unsaturated fatty acids as Sullivan. Although some lecithin and cephalin are present, the main portion of the acetone-insoluble fraction is composed of some other lipide compound. A microscopic examination shows that the aleurone and testa layers of the bran contain more lipides than the other layers, although the endosperm showed no fat by this method.

The Ash Content of Flour

Sullivan (116) finds that the total ash content of wheat averages about 1.86%. The bran coat and the germ contain 20–25 and 10–15 times as much ash as the endosperm, respectively. For this reason the ash content of flour can be used as a reasonably accurate criterion of the degree of separation of the bran coat and germ from the endosperm. Flours containing too high a proportion of bran coat and germ, and hence of ash, do not make acceptable white bread and biscuit. The maximum limit (64*a*) for ash is $\frac{1}{20}$ of the protein plus 0.35%.

The inorganic constituents (116) of wheat, patent flour, and bread are shown in Table 29.

TABLE 29

INORGANIC CONSTITUENTS PRESENT IN RELATIVELY LARGER QUANTITIES IN WHEAT, PATENT FLOUR, AND BREAD
(*Sullivan*)

Inorganic constituent	Wheat [1] %	Patent flour %	Bread %
Total ash	1.86	0.45	2.77
Potassium	0.571	0.168	0.200
Phosphorus	0.428	0.113	0.140
Sulfur	0.194	0.165	0.192
Magnesium	0.173	0.029	0.040
Chlorine	0.055	0.051	1.005
Calcium	0.048	0.016	0.080
Sodium	0.009	0.003	0.660
Silicon	0.006	0.005	0.005

[1] Calculated to dry basis.

Phosphorus is found in inorganic combination and in organic combination in phytin, nucleic acid, and lipids.

Potassium (116) probably has some direct bearing in the translocation of sugars and in starch formation. A potassium deficiency influences the respiration rate of plants and may have some role in the activity of diastatic enzymes.

Magnesium (116) is found in excess of calcium in plants, whereas the reverse is true in animal tissues. It is present in chlorophyll, and it takes some part in the transfer of phosphoric acid through plant tissues. It may exist in the wheat pericarp as the magnesium salt of inositol phosphoric acid. It is found in larger quantity in stronger than in weaker wheats, and there is a correlation between the percentage of magnesium and protein content.

Calcium is essential for the growth of plants. It is present in both inorganic and organic combination. Plants (116) deficient in calcium are unable to assimilate nitrates and accumulate carbohydrates in large quantities. The potassium (119), magnesium, and phosphorus content of glutens in three grades of flour are as follows: the calcium content is highest in glutens of highest strength, lowest in those of least strength, and potassium and magnesium increase as the tenacity of the gluten decreases.

Calcium acid phosphate is often added to soft-wheat flour and sometimes to high grades of flour. This practice is very common in the South. A great deal of this flour is used in quick breads, particularly biscuits.

The inorganic constituents (116), iron, manganese, copper, zinc, boron, cobalt, iodine, fluorine, and nickel, all play a significant role in plant physiology. The addition of certain of these rare minerals, in as little concentration as one part per million, to nutrient solutions in which plants are grown permits normal growth and production, although too great a concentration of some of these elements has undesirable effects.

Sulfur, according to Greaves and Bracken (70), averages 0.18% for 21 varieties of wheat. The correlation between total sulfur and total nitrogen is highly significant. The sulfur is in organic form. A sulfur-bearing constituent (50) has been reported as present in the ether-petroleum extract of flour.

The iron content of wheat (39) is 0.0037% on a 13.5% moisture basis. The iron content of the different separations of the wheat as obtained by Andrews and Felt (39) is: patent flour 0.00078, first clear 0.0019, second clear 0.0062, red dog 0.0113, shorts 0.0127, bran 0.0126, and germ 0.0086%. In general there is a linear relationship between iron content and ash content. However, bran and shorts contain about the same amount of iron but bran contains 50% more ash than shorts.

Carbohydrates

The starch of flour has been considered.

Sugar. Flour contains small amounts of sugars. The content of maltose is ½–1%. The amount of sucrose averages approximately 1% but may reach 2–3%. Dextrose may not be present in the flour but is found in bread dough. Dextrin is present in the flour in very small quantities.

The Proteins of Flour

Osborne (100) in his classical work on the wheat-flour proteins reported only a small fraction soluble in water. This fraction contained leucosin and albumin, plus proteose or non-protein nitrogen. A small globulin fraction, extracted by dilute salt solution, constituted about 0.6% of the wheat kernel. Gliadin, a prolamin, constituting about 40% of the total protein, was soluble in alcohol. The remaining protein, called glutenin, was found to be insoluble except in dilute acids or alkalies.

Effect of salts on protein extracted. Gortner, Hoffman, and Sinclair (69) found that $N/1$ solutions extract the following average percentages of the total wheat-flour proteins: KF, 13; KCl, 23; KBr, 37; and KI, 64. They showed that the amount of protein extracted varied not only with the nature of the salt used but also with its concentration.

For increasing peptizing (69) effect on wheat proteins the following anions arrange themselves in a lyotropic series: $F < SO_4 < Cl <$ tartrate $< Br < I$. The cations have a less distinct effect on solubility of the flour proteins but give the following order of peptization: $Na < K < Li < Sr < Mg < Ca$.

Rich (107) has shown that the amount of protein extracted or peptized by $N/2$ $MgSO_4$, 10 per cent NaCl, and $N/4$ NaCl solutions varies directly with increasing ash content of the flour. In general, the maximum peptization occurred with $N/4$ solutions. A further increase in salt concentration causes dehydration and eventually salting out of the protein micelle.

The protein fractions of gluten. Rich (107) states that the number of protein fractions obtained depends on the method of isolation. If the dispersion agent or method is changed there is no established limit as to number, quantities, or nature of the proteins isolated (56, 94, 107). Blish (58) has summarized the literature and his observations on wheat gluten. Some technics developed for fractionating proteins since Osborne's studies include the ultracentrifuge, electrophoresis, diffusion measurements, and new fractionation procedures. Blish (58) concludes that Osborne's division of gluten into two proteins is no longer acceptable. There is no solvent that dissolves gluten so completely that it can be separated from all non-protein impurities. Without suitable solvents to disperse gluten molecularly, most of the electrophoretic studies have been made on gliadin. Gliadin in these tests is inhomogeneous. Gluten can be dispersed in solutions of alkali, but the dissolved gluten undergoes irreversible changes. All gluten fractions have also been found to be inhomogeneous. Blish (58) suggests that non-homogeneity of gluten may be due to aggregation rather than to several components. Although fractions of gluten may be composed of more than one protein, for convenience they are still called gliadin and glutenin.

Pence and Elder (103) found that the albumin proteins of wheat consist of at least six components, similar in molecular weight, but differing in electrophoretic properties. The albumin is characterized by a high tryptophan content.

Barmore (52) fractionated wheat gluten into components that differed in viscosity and solubility. He interpreted differences in viscosity to be brought about by variations in length of the rod-like protein molecules. The length of gliadin molecules was about 15 and 26, gluten about 41, and glutenin about 47 times longer than the thickness of the ellipsoidal particles. Gliadin, the shortest and most symmetrical, was the most soluble. "The data add further evidence to that in the literature that gliadin and glutenin are part of a complex protein system differing systematically in physical and chemical properties with no clear-cut distinction between the two."

Heat denaturation of gluten. The glutenin fraction (58) is far more sensitive to heat than the gliadin one. Gluten (58) follows the general denaturation pattern of proteins, but differs from the globular proteins of egg white and hemoglobin in some respects. Although hemoglobin is readily denatured by sodium salicylate, gluten protein can be alternately dispersed by and salted out of solution of this chemical without significant changes in its original properties.

Pence et al. (102) found that time, temperature, *p*H, moisture, and salt content, all affected denaturation of gluten and gliadin by heat. The rate of denaturation was very slow at 70°C, but increased as the temperature was elevated to 90°C. Baker and Mize (46) in testing the effect of temperature at ordinary rates of heating on doughs found that coagulation of gluten is not perceptible below 75°C, progresses slowly, and requires long-continued heating for complete coagulation. Denaturation rates of gluten (102) of low moisture content were negligible at temperatures of 80–90°C, but increased to a maximum at moisture content of 35–40%, then decreased slightly with still higher moisture content. (This probably has a relationship to the baking times of such products as biscuits and popovers.) Gliadin denatured at a much slower rate than gluten and was characterized by an induction period.

Lecithoprotein and lipoglutenin. Blish (56) states that flour may contain a lecithoprotein somewhat similar to that found in egg yolk. Olcott and Mecham (99) state that several investigators have observed that gluten contains 5–10% lipids, only a small fraction of which can be extracted with petroleum or ethyl ether. This complex may be formed when water is added to the flour (93). At least three times the amount of lipid normally present can be bound, phospholipids preferentially, by the doughing process (99). Most of the bound lipid is associated with the glutenin. The term "lipoglutenin" is suggested for this complex.

Gliadin. Gliadin, either as a multiple protein, or as a component of the gluten complex, is soluble in 60–70% alcohol. In water it swells to a sticky mass, being least soluble at its isoelectric point, about *p*H 6.5. With increasing acidity it becomes more soluble, reaching a maximum with a *p*H range of 2.0 to 3.0. With hydrogen-ion concentration greater than *p*H 2 the solubility decreases gradually. With increasing alkalinity, the solubility of gliadin increases more rapidly than on the acid side, up to *p*H 13.1, the most alkaline of the solutions used by Tague (125).

Glutenin. The glutenin, classified as a glutelin, is responsible for the desirable baking qualities of wheat flour, qualities not possessed by any other cereal. Gliadin (58) presumably functions chiefly as a binding or adhesive agent for the more labile glutenin particles. Glutenin is insoluble in water but is increasingly soluble in dilute acids and alkalies. Glutenin swells in water at room temperature. Sharp and Gortner (109) state that the maximum solubility occurs on the acid side at *p*H 3.0 and on the alkaline side at *p*H 11.0.

Isoelectric point of gluten proteins. Bailey has tabulated the isoelectric points of flour proteins obtained by various investigators (41). These data were obtained by various methods (some are not considered accurate now) and vary widely. Bailey suggests the following isoelectric points: for gluten, *p*H 6.1; for gliadin, 6.85; and for glutenin, 5.5. Kent-Jones and Amos (87) suggest for gliadin *p*H 6.3 to 6.7, and for glutenin 5.2 to 5.6.

Amino acid composition. Pence et al. (101) determined the amino acid composition of seventeen different flours. The composition of the gluten was essentially uniform, despite the wide types of wheat with varying protein content used in the tests.

Factors Affecting the Baking Quality of Flour

All the constituents of the flour, the other ingredients used and their proportions, the method and extent of mixing, and the fermentation procedure affect the performance of the flour in baked products. In this chapter, the term baking quality refers to the ability of a flour to make large well-piled loaves of bread.

Fineness of division of flour. Too coarse or too fine flour particles (104) give smaller loaves of bread with less desirable color of crumb. Overgrinding injures the starch granule, and swelling (36) occurs at the site of injury, but the starch of the granule is not completely dispersed. Badly injured granules may swell to nearly the same extent as uninjured granules that are boiled. Although diastase acts on the whole starch granule slowly, if at all, with many injured granules, diastatic enzymes (37, 86) convert starch to sugar more rapidly so that the rate of fermentation is increased. Although severe overgrinding (37) reduces the baking strength, at the same time it increases the water absorption of the flour, owing to the injured granules. Usually when baking strength is reduced the hydration capacity is also reduced.

Maturing of flour. Changes brought about by natural aging improve the baking quality of the flour (62, 110). Some of these changes are: increases in acidity, in free fatty acids, and in acid number of the fat (88).

Flour improvers. Papain is inactivated by such compounds as $KBrO_3$, KIO_3, sodium metavanadate, and ascorbic acid. It is activated by compounds containing SH groups such as glutathione and by H_2S. Since the proteolytic enzymes of flour or papain-like they react similarly with most compounds. $KBrO_3$ or ascorbic acid may be added to flour to increase its baking strength. A specific flour needs a definite amount of a given improver, too much being worse than none at all. No two improvers (122) react exactly alike. Some react rapidly, others more slowly, and each may have an optimum *p*H activity. Most flour improvers are oxidizing agents, but ascorbic acid is a reducing agent. Hence the method of its action is of interest to cereal chemists. Sullivan et al. (122) present considerable evidence that the labile sulfur groups of the gluten or similar reducing groups are connected with the reaction.

Lipids and flour quality. It has been shown by many investigators (61, 88, 93, 117, 122) that ether extraction of flour injures its bread-baking qualities. The loaf volume is decreased, and both the dough and the crumb of finished bread of such extracted flour are more rubbery and tough. The baking quality of the flour is restored by adding the extracted fat to the ingredients during mixing. Nothing has been found (117) which equals the flour fat in bringing back to normal an extracted flour, since germ fat, cottonseed oil, lard, and many other shortenings only partially restore the baking quality. Lecithin added in small amounts to normal flour (117) gives a smoother-feeling dough but has little effect on baking properties.

When flour ages, the enzymes of the flour bring about hydrolysis of the fat, free fatty acids being formed. Kozmin (88) attributes part of the beneficial effects of aging flour to the formation of these fatty acids. The hydrolysis of the fat (117) is more rapid at higher temperatures. With overaging the flour deteriorates, giving a gluten that is bucky, lacks tenacity, and tears easily. If the fat is extracted from an overaged flour with ethyl ether and fresh flour fat is put back into the flour in the amount originally present, the baking quality of the flour becomes normal. The unsaturated fatty acids of the overaged flour have become oxidized.

Sullivan (117) has shown that the higher-saturated fatty acids have only a very slight adverse effect on flour. The unsaturated fatty acids such as oleic, linolic, and linolenic produce "short," tough, and brittle glutens when added to sound normal flours. But these unsaturated acids also have only a slight detrimental effect on the baking quality of flour. It is when the unsaturated fatty acids have become oxidized that they have a marked effect on the baking quality of the flour.

It has long been known that a small amount of fresh wheat germ added to a patent flour (117, 120) has a very deleterious effect on the baking quality of the flour. Sullivan et al. (120) have shown that the wheat germ contains glutathione, although there is little if any in patent flour. This glutathione can be extracted from the germ by water, and injures the baking quality of the flour. It has been shown that, if $KBrO_3$ or KIO_3 is added along with the germ, the injurious action is reduced.

Starch. Harris and Sibbitt (77) separated the starches from twenty different flours from a variety of wheats. In order to compare their baking quality in bread a constant dry gluten substrate was prepared from hard red spring wheat and used in all bakings. Marked differences were found in the baking quality of starch from different varieties, one variety from a soft red winter wheat producing the best bread. Starch qualities are supposed to be inheritable, although some evidence indicates that environmental factors also play a role. It is suggested that part of the difference in baking quality may come from greater granule injury during milling of the hard-wheat varieties.

Properties of dough. For bread, a dough is made by mixing in the proper proportion water, flour, yeast, and salt (shortening can also be used if desired). Although the dough's physical and chemical properties are affected by each ingredient and its proportion, the dough as a whole has certain characteristics. Like all other food products it ages or changes with time. It (73) possesses characteristics of both solids and liquids. It can be deformed by force, but with removal of the force, because of its elasticity, the original shape is regained, provided that the deformation has not exceeded a certain degree. If left to stand, dough behaves like a liquid, since it flows to a certain extent. A few of the properties of doughs are viscosity, plasticity, elasticity, mobility, extensibility, and tensile strength. These properties can be measured by suitable methods. The viscosity and shear modulus (73) are two properties related to baking quality. A perfectly elastic solid, if loaded, stretches, but its recovery with the removal of the load is equal to the stretch. For a plastic material like dough, according to Halton and Blair (73), "the stretch is partly elastic (recoverable) and partly plastic (non-recoverable)." To determine the shear modulus of a dough it is necessary to measure both the stretch and the recovery.

The viscosity and modulus of the dough (73) are affected by the proportion of water used and also by temperature, the decrease amounting to 10 and 5%, respectively, per 1°C rise in temperature. The modulus (73, 98) and also the viscosity are decreased by excessive mixing. However, after mixing the dough tends to return to its original condition after standing for a time, the extent and rate depending upon the flour and the treatment the dough has received. The viscosity and modulus (73, 98) decrease during fermentation.

Elasticity and tenacity (44, 59) decrease as fermentation progresses. The elasticity and extensibility (44) increase with a rise in temperature. The increase in extensibility of the dough during baking is of great importance, for without this quality the cell walls of the dough would break and coalesce before the temperature at which the protein coagulates is reached. As a result the volume would decrease during baking.

Salts may decidedly affect dough characteristics, probably through their effect on the gluten. NaCl up to 2% (59) toughens or strengthens the dough. $CaH_4(PO_4)_2$ (44) causes a slight increase in extensibility; $CaSO_4$ and $MgSO_4$ have no effect.

Dough structure. When water is added to flour a partly elastic, partly plastic solid is formed. At temperatures at which mixing usually occurs the starch granules do not swell appreciably, at most 15% (35). A dough (124) made from flour containing 11% protein has less than 7% protein, and the starch and water constitute about 46% each. The protein in the dough, however, absorbs water, about 200% of its weight, and swells (35). Thus the relative volume of the protein in relation to the starch increases enormously after the addition of water. This, however, is not sufficient to impart the familiar structure of bread dough. Mixing and kneading are necessary. During this process the swollen protein particles are brought in contact with each other, and since they have acquired adhesiveness and stickiness by absorbing water, they make contacts, which allows the gluten to form a continuous network throughout the dough, or the gluten becomes attenuated.

Hlynka and Bass (79) suggest that reducing carbohydrates may act as cross-linking agents between protein chains in the elaboration of a three-dimensional network. Thus part of the adhesiveness of the gluten would result from these bonds. The feel of the dough changes from a firm, rather hard, to an elastic, springy mass. The gluten contacts or links (73) are not equally strong throughout the dough. Hence, when the dough is stretched some contacts break, others hold. When CO_2 inflates or expands the dough these strands of dough are stretched. In this process the pores of the dough become enlarged, the cell walls thin and fine, and the gas/dough surface area enormously increased. Kneading or punching during fermentation serves two purposes. It forces part of the gas out of the dough, thus reducing the size of the pores, and also helps to distribute the increased yeast cells so that more numerous gas pockets are formed, thus increasing the fineness of the dough structure.

The gluten may be likened to chewing gum and the starch to minute tapioca or marbles imbedded in the gluten meshwork. The sugar and salts are dissolved in the free water; the fat, not being soluble in the water, is distributed on the surfaces of the gluten and starch throughout the dough.

Gluten. Gluten is largely responsible for the structure developed in dough and is described in the preceding paragraph. After flour is made into a stiff dough and kneaded a short time, the starch can be washed out, leaving a small fraction of the original dough which is called crude gluten.

Gluten is composed principally of hydrated proteins of the flour with some entangled starch, lipids, and mineral salts. The amount of these constituents varies with the manipulation in washing, the kind of water used, and the characteristics of the flour. These washed-out glutens may vary in color, feel, elasticity, extensibility, tensile strength, the volume attained when baked, and in other properties. They can be dried (33, 45, 75) and in this way furnish gluten from a common source to test differences in starches and other constituents.

It is difficult (112, 123) to wash gluten from dough that has been overmixed, although the reason for this is not known. Swanson (123) suggests that the gluten fibrils either break by the continuous stretching or they become very attenuated. In the attenuated condition the gluten adheres so strongly to the surface of the starch granule that separation is difficult. No evidence (112) of chemical decomposition is obtained during excessive mixing of doughs, even when a firm, dry dough is mixed so long that it is converted to a soft, sticky dough which lacks tensile strength.

It also becomes impossible (109, 113) to wash gluten from a dough as fermentation progresses, although it is reported possible (109) if sufficient electrolytes are present in the wash water.

Glutens from the different classes of wheat. The glutens from hard wheats have the qualities for producing excellent bread with thin cell walls and a porous structure. The early established standards (124) for bread were based on the performance of hard red spring wheats. The Turkey group of hard red winter wheats (124) were soon included in these standards. The soft wheats cannot be used easily for bread but make excellent pastry, cake, and other products. Hence the standard of excellence of a flour is really determined by the way it performs in a particular product.

The viscosity of gluten dispersed in 10% sodium salicylate (76) is greatest from hard red spring wheat, followed in the order named by hard red winter, soft red winter, emmer, and durum. The relative placing is attributed (76) to varying micelle size of the glutens, those with the smallest particles giving the least viscosity at equal protein concentrations. This is in agreement with Gortner and Doherty's (67) suggestion that the size of the gluten particle is a factor in determining its properties. Strong flours yield glutens with nearly "perfect colloidal" gels with gluten micelles in a less dispersed state, whereas the weak flour glutens are less colloidal or more highly dispersed.

Hydration capacity. The absorption of water (35) is used as a criterion of flour quality by the baker. The greater the hydration capacity, the more loaves are obtained from a barrel of flour. In addition the amount of water in the loaf as it comes from the oven depends in part upon the amount of water in the dough. The rate of hydration as well as the capacity vary with different types of flour. A strong gluten (67) has a faster rate of hydration and also a higher maximum hydration capacity than a weak gluten.

Alsberg (35), quoting Newton and Cook, states that half of the water of a dough is bound, the other half is free. In the dough, the gluten absorbs about 200% of its weight of water; the starch absorbs about 30%, but, since the starch composes about $\frac{4}{5}$ of flour, it holds about half the total water.

Bound water. Skovolt and Bailey (114) in their tests find that the average amount of bound water is 51.4% of the total water present. Vail and Bailey (126) find no significant differences in bound-water content of doughs mixed 1-, 3-, and 10-minute periods, the amount being 34.83, 36.46, and 35.06%, respectively. The hydration capacity is 28.6% based on bound water held per unit weight of dry matter.

Kuhlmann and Golossowa (89) find the water-binding capacity of the flours they tested to be in the following order: soya, rye, corn maize, durum wheat, soft wheat, and potato. For winter (whether hard or soft not stated), durum, and spring wheat flours (composed of 75% of the wheat) the bound water is 46.4, 46.4, and 44.4, and the water-absorbing capacity is 50.0, 70.4, and 60.2%, respectively. Separate components of the cereals vary in water-binding capacity, rye starch binding 78–80, wheat starch 40–42% of the water. In general, though not always, there is a greater water-binding capacity with increased protein content.

The water-binding capacity of bread doughs increases sharply during baking, a dough having a water-binding capacity of 60% changing to about 85% in hot bread.

The factors (89) which increase the water-binding capacity of the dough decrease moisture loss in baking, increase the weight of the baked bread, and reduce the loss during aging of the bread. Both the method of making the dough and the materials used influence the water-binding capacity. Doughs made by a straight-dough method bind more water than those made by the sponge method. The addition of maltose and buttermilk increases the water-binding capacity.

Factors affecting hydration of gluten and flour. *Overgrinding* increases the hydration capacity of a flour through increased absorption by starch.

Salts. Different salts depress the hydration capacity of the gluten in different degrees, *i.e.,* in the order of a lyotropic series (see the section on proteins). The salts bringing about the change in hydration capacity may be found in the flour, or added in the form of NaCl, baking powder, or bread improvers.

Alkalies. The hydration capacity of gluten on the alkaline side of the isoelectric point reaches its maximum capacity at a *p*H 11.0. Beyond a *p*H 11.0 the gluten dissolves very rapidly with increasing alkalinity. Since gluten proteins tend to imbibe water and disperse in a weakly alkaline medium, doughs with a slight alkaline reaction are sticky. With excess alkali they become yellow and develop a soapy taste. Since the proteins are peptized readily with alkali, a product with a *p*H higher than 7 is quite tender. Thus chocolate cakes and gingerbread with excess alkali (soda) are very tender, though the cell walls are very thick.

Acids. The hydration capacity of gluten is markedly influenced by acids as well as by salts and alkalies. It is increased with increased hydrogen-ion concentration until a *p*H of 3.0 is reached. With a *p*H lower than 3.0 the hydration capacity is decreased. Gortner and Sharp (68) have shown that the various acids produce a maximum hydration at *p*H 3.0. On the acid side of the isoelectric point the gluten is not dipersed as rapidly as on the alkaline side, so that doughs with an acid reaction are more tenacious, and not so sticky as ones with an alkaline reaction. During fermentation of bread the development of acids gives an acid reaction to the dough, increasing the hydration and solubility of the proteins and thus the tenderness of the resulting bread.

Temperature. At temperatures of 8–9°C the hydration capacity of gluten (87) is low, but with increasing temperature hydration is not only greater but also more rapid.

Protein content and loaf volume. Flours with strong glutens perform well in bread, yielding good volume and superior crumb, and under many conditions the quality of the bread obtained is in direct ratio to the protein content (54). There is some evidence (82) that the greater loaf volume, at least in part, is because of the better retention of CO_2 by the dough with increased protein content. When flours of similar protein content (34) are used and gas production is not a limiting factor, loaf volume is essentially a meausre of protein content. With constant dried gluten substrate (77) used at 10, 13.2, and 16% levels, loaf volume is in direct ratio to protein content. When dried gluten prepared from various types of wheat (75) is added to a soft-wheat, low-protein flour to bring the protein level to 14%, the volume is markedly increased with hard red spring wheat glutens, followed by hard red winter wheat glutens, whereas glutens from soft and durum wheats have negligible effect. Among hard red wheat flours the baking strength is related to the protein content in linear fashion and very highly correlated with it. However, there is wide variation in protein quality (108) among varieties, and the protein quality within a variety varies with the naturally occurring protein level.

Fifield et al. (63) used 589 samples representing 10 varieties of hard red spring wheat grown for 4 crop years under a wide range of climate and soil conditions. They found the relation between loaf volume and flour protein was linear within the limits of protein encountered, approximately 8.5 to 18.0%.

Fermentation. The production of gas in the dough to render the bread porous is known as fermentation. Both yeast and bacteria are used to produce gas, bacteria producing the gas in salt-rising bread, yeast in ordinary bread.

Microorganisms in bread making. Fuller (66) states that the "microorganisms associated with the production of bread may be divided into three main groups: (*a*) the yeast *Saccharomyces cerevisiae,* carefully purified and selected strains of which are purposely added to the dough; (*b*) certain bacteria, which, introduced either purposely or accidentally, assist in the development of the gluten and give rise to characteristic flavoring products; and (*c*) the unwanted organisms, *B. mesentericus,* torulae, and moulds, which are introduced chiefly from flour, air, and perhaps water, unintentionally either into the dough or onto the baked loaf."

It (66) seems likely that attention has been confined too much to selecting and purifying yeasts in relation to their CO_2-producing powers and that side reactions, *e.g.,* those involving the essential flavoring ingredients, have been neglected. The work of a Russian microbiologist is cited (66) who examined the flora of a number of samples of "leaven." The dominant organism in all was *Lactobacillus panis acidi,* with *Streptococcus lactis acidi* and others in small numbers. Adding *Lactobacillus panis acidi* to yeast gave a bread with flavor superior to that of bread in which yeast alone was used.

Halton and Blair (73) state it has usually been considered that the change in dough quality during fermentation, known as ripening, is due to chemical actions associated with yeast activity. But experiments show that the presence of yeast has little effect on the dough's physical properties or on the way these change during fermentation, its chief role being that of a gas-producing agent.

Enzyme action in fermentation. The yeast contains an enzyme, zymase, that produces CO_2 and alcohol from the sugar. During fermentation many changes are occurring in the dough. The flour enzymes as well as the yeast enzymes bring about definite reactions. The chief amylolytic enzyme of the flour, diastase, produces maltose from starch. Flour contains some initial sugar but this is used up in gas production and it is essential for sugar to be formed for new gas production. Yeast also contains some diastase. Sugar is usually added to bread dough. It is not essential, but fermentation is more rapid and the flavor of the bread is preferred by many consumers.

Acidity and other changes in dough during fermentation. As fermentation of the dough progresses, its acidity is increased, although this increase (72) is not great and the major part occurs during the first hour of fermentation. There is no relation (72) between rate of gas production and rate of change of *p*H. Bailey and Sherwood (43) have shown that the increase is largely due to CO_2, although some lactic and acetic acids (81) are also formed during fermentation. The *p*H of the baked bread (43) is always higher than that of the dough from which it is baked. See Table 30. As fermentation progresses (109) there is a decided increase in the imbibitional capacity of the glutenin as influenced by lactic acid.

TABLE 30

Hydrogen-Ion Concentration (in Terms of *p*H) and Titratable Acidity of Bread Dough Suspensions (*Bailey and Sherwood*)

	*p*H	Dough 1 titratable acidity	*p*H	Dough 2 titratable acidity
1. Fresh dough	5.76	1.10	5.75	1.10
2. Fresh dough after 5 hours	5.24	3.36	5.18	3.50
3. Baked bread	5.43	....	5.38	....

Johnson and Bailey (82), in studying the effect of hydrogen-ion concentration on dispersion of the gluten of the flour in cracker dough, have found that as the acidity increases the percentage of proteins is dispersed or the protein in the aqueous extract of the fermented dough increases. The results up to the time of addition of $NaHCO_3$ before baking are given in Table 31.

BREAD

After the long bread hearings pursuant to the establishment of definitions and formulation of standards of identity of bread, the evidence was summarized in "findings of fact." This was published in 1952 in the

TABLE 31

Effect of Fermentation upon Dispersion of Proteins of Flour
(Johnson and Bailey)

Hours fermented	*p*H	Dispersed protein based on proteins in flour, %
0	5.95	15.14
2	....	17.70
4	....	20.60
6	5.49	31.76
8	5.12	77.22
10	4.60	87.42
12	4.26	89.42
16	3.92	92.14
18.5	3.86	93.70

Federal Register (64*c*) along with the promulgated standards of identities of bread. The ingredients permitted and those prohibited are listed with the reason for the action taken.

Standards of identity were established for bread (white bread), enriched bread, milk bread, raisin bread, and whole-wheat bread.

Although specific surface-active agents, eggs, malt products, dusting flours, inactive dried yeast, yeast foods, oxidizing agents, mold inhibitors, and defatted soy flour for enzymatic purposes are permitted in bread in small amounts, the ingredients to be considered here are flour, fat, liquid, sugar, salt, and yeast. The right treatment of the whole mass gives a loaf of good volume and a crumb with thin cell walls and immense area, owing to the porosity created by the CO_2. The part that different factors and constituents play in the dough structure, and hence, in bread, has been discussed in the preceding pages.

Proportion of ingredients used in bread. The American Association of Cereal Chemists has committees for the standardization of the baking and other tests. The latest publication is *Cereal Laboratory Methods.* Cathcart (135) gives a history of the baking committee.

Flour. It is customary in reporting the proportion of ingredients used in bread to give percentages in relation to 100 parts of flour. For example, if 100 grams of flour is used with 2 grams of yeast, 3 of sugar, 3 of fat, and 60 grams of water the results are reported as 2, 3, 3, and 60% of the different ingredients, respectively. It requires about ¾ pound of flour to produce a pound loaf of bread, though the exact amount varies with the hydration capacity of the gluten.

Fat. The proportion of fat used in different bread varies. No fat is used in some hard breads. The usual amount of shortening (64*c*) is

2–6%. The amount may be greater for rich, sweet goods or for shortbread. The effect of fat on the quality of the bread is discussed later.

Liquid. The optimum proportion of water or liquid milk for a good loaf volume varies with the hydration capacity of the gluten in the flour that is being used. This proportion is reported to vary from 51 to 71%. Good bread flour requires 60–65% of water. Soft-wheat flours, which have weaker glutens, require a lower proportion of water. The extensibility and tenacity of the dough increases with increasing water content until optimum imbibition is reached, about 64% for the flour used to obtain the data in Table 32. Beyond the optimum amount of water, the tenacity and extensibility of the gluten decrease.

TABLE 32

EFFECT OF INCREASING WATER IN A DOUGH (*Bailey and Le Vesconte*)

Absorption, %	Extensibility	Reading for tenacity, millimeters
59	18.65	125.0
60	18.80	122.0
61	18.90	121.0
62	19.50	117.1
63	19.77	114.7
64	21.00	99.7
65	20.96	94.5
66	20.48	94.5
67	19.66	92.3

Sugar. The proportion of sugar used in different types of breads and rolls may vary widely. In bread 2–6% sugar with an average of 3% (64*c*) gives an adequate amount for yeast growth. If sweeter bread is desired more sugar can be added. With large proportions of sugar, around 16% (64*c*), sweet goods are produced. It has been reported (130) that sucrose, fructose, glucose, and invert sugar ferment at about the same rate in dough, the volume of the loaf increasing with increase in sugar to 3%, but decreasing when more than 6% of sugar is added. Lactose (148) depresses loaf volume. Maltose (147) does not perform as well in dough as does sucrose.

Salt. About 1.5–2% of salt is added to bread. NaCl is not added to some breads made for special dietary purposes. Dunn (137) states that the function of salt in bread is threefold: it stabilizes fermentation, strengthens the gluten, and not only adds but develops flavor, owing to its effect on the flavor of other ingredients. If salt is not added to the dough, fermentation takes place very rapidly and the bread is too coarse; if too much is used, fermentation is slow and the bread is firmer and more compact.

Yeast. Commercial yeast may be purchased in two types, the compressed in cake form, and the dry in granular form. Yeast is a living plant. As such it is perishable. Most living plants when dehydrated below a certain moisture content die. There are, however, many types of yeast. Certain types were developed that, with certain procedures in cultivating and drying, can be dehydrated, yet retain their viability when reconstituted with water. With the added moisture and food of the bread dough the yeast plants multiply rapidly to produce a large quantity of CO_2. For best results the temperature of the water in which the yeast slurry is formed should vary. It should be lukewarm, about 27–30°C (80–86°F) for the compressed yeast; but warm, about 43–46°C (110–115°F) for the active dry yeast.

After yeast is added to the bread a period of time elapses before the bread is baked. This period, the length of which depends upon the proportion of ingredients and the kind of yeast used, is called the fermentation period. Bakers call it "proofing" and housewives "rising."

As a general rule (141) bakers use 2–3% of yeast, although the amount may vary from 1 to nearly 6%. For home and school the amount may be increased according to the length of time allowed for the fermentation period.

Finney et al. (140) detected cadmium spectrographically in the ash of bread baked from dough in a bread mixer with cadmium-plated planetaries. Yeast fermentation had been inhibited in this dough. The effect of varying concentrations of cadmium chloride along with salts of other metals (chromium, nickel, tin, zinc, magnesium, and manganese used in plating and in aluminum and steel alloys) on yeast growth were tried. They found the enzymes of yeast were inactivated wholly or in part by all concentrations of some of these metallic salts and only at certain concentrations by others. They recommend chromium, nickel, or tin as being biologically safe for plating surfaces coming in contact with the yeast-fermented doughs.

Influence of added fat on bread quality. Carlin (134) summarizes the function of fat in bread dough. He states that the preferred fats for bread making are lard and blended shortenings. Shortening improves the volume of bread, the improvement with most flours being progressive with fat increase to 2% of flour weight. Some very strong glutens may require 3–4% of shortening. Fat gives a more velvety and softer crumb and improves the grain of bread, although too much results in a coarse grain. Shortening increases the tenderness of the crust and crumb, the luster of the crust and sheen of the crumb, and the machining qualities of the dough. It materially enhances the keeping quality, the increase being progressive with 1–6% fat.

The fat (134) is spread over the surface of the gluten and the starch. The influence of fat in the dough depends to a great extent on its insolubility in the other ingredients and its adhesion qualities. A surface-active agent which affects the surface tension of the fat and water and influences the spreading of the fat, increases the tenderness and keeping quality of the bread. Strandine et al. (155) suggest that the monoglycerides may decrease the swelling and water imbibition of the starch during baking, thus more water is available for gluten hydration.

Baker and Mize (47) found that oils improved the loaf volume over that of control loaves with no fat, but in turn semisolid or plastic shortenings gave better volume than the oils. These workers showed that, if a very hard fat (completely hydrogenated) was ground finely and added to the oils in concentrations of 0.2–2%, the loaf volume was increased over that of the oil alone. They suggested that the finely dispersed hard fat plugged the holes responsible for gas leaks in cell walls of the dough, resulting in increased volume.

The surface-active agents permitted in bread. Many reports occur in the literature on the effect of surface-active agents or emulsifiers on the softening of bread crumb and the retarding of staling. Edelman and Cathcart (138) tested 24 of these emulsifiers. Of this number 5 proved to be good softeners of bread crumb: glyceryl monostearate, glyceryl oleostearate, polyoxyethylene stearate, sorbitan monostearate, and polyoxyethylene sorbitan monostearate. Of these, polyoxyethylene stearate was the most effective. Bread containing 1% glyceryl monostearate approached but did not equal the softness of bread crumb containing 0.5% polyoxyethylene stearate.

Before the bread hearing for the promulgation of the 1952 bread standards (64*c*), some of these emulsifiers were being used in bread. When the standards of identity of bread were formulated (64*c*), the use of the last three emulsifiers named above (138) was forbidden. However, bakers of bread, after the adverse testimony in the hearings, had removed them from bread before the standards were set. The emulsifiers permitted are: lecithin, the mono- and/or diglycerides (commercial preparations of these have an average content about as follows: 40% mono-, 55% di-, and 5% triglycerides) of the fat-forming fatty acids (except lauric), and/or the diacetyl tartaric esters of mono- and diglycerides (except lauric) or a combination of two or more. The monoglycerides are more effective emulsifiers than the diglycerides. The amount of the emulsifiers permitted is about 20% of the weight of the shortening.

Milk and milk solids and bread quality. Fluid milk is often used for the liquid in homemade bread and rolls. It is usually scalded and cooled before use. Larson et al. (149) give a good historical review of the work on heat treatment of milk. They state that dry skim milk solids are "desirable ingredients in bread since they supply valuable proteins, vitamins, and minerals and frequently improve the appearance, as well as the palatability, toasting, and keeping quality of the bread." However, for the non-fat dry milk solids to have a high water-absorbing capacity, to prevent their softening the dough during fermentation, and to produce a quality of loaf of good volume, the milk must be preheated before drying. The optimum preheating temperature and time seem to vary with different formulas and technics. Ashworth and Kruger (128) state that with fat in the formula the milk should be heated at 80°C for at least 15 minutes. They add that it is generally assumed by the industry that optimum preheat treatment is gained by heating the milk at 82°C for at least 30 minutes. Samples (149) of milk heated at 63–68°C for 30 minutes did not perform well in bread even though they received high heat treatment during the subsequent drying process. The minimum heat treatment for optimum loaf volume is between 68° and 74°C for 30 minutes. The factor that causes breakdown of the gluten matrix resides in the milk serum proteins (148), and heat destroys the action of this component. The Minnesota investigators (144) have published a series of papers on their tests of the milk depressant of loaf volume. In a paper published in 1953 they state that both the serum proteins, lactoglobulin and lactalbumin, depress loaf volume, both are composed of a number of proteins, but the overwhelming majority of the depressant is in the lactoglobulin fraction. It is possible (149) that "any milk powder can be made to produce an acceptable loaf of bread if enough time is taken to find the optimum bromate level, absorption, mixing time, salt concentration, shortening level, fermentation time, etc., for a given flour."

For commercial bread to be labeled "milk bread" the standards of identity require 8.2 parts of milk solids by weight per 100 parts of flour. Milk and various milk products may be used in other types of bread, without so stating on the label. However, it is implied that the amount of milk solids is less than in milk bread.

Length of the fermentation period. The total length of the fermentation period depends upon the proportion of yeast, the temperature at which the sponge or dough is kept, and the richness or type of dough. The first rising often requires about 70% of the total fermentation time, and the dough should double in bulk. The dough is then punched down and worked lightly to allow the gas to escape and to redistribute the gas cells. After the second rising the dough is usually punched and placed in the baking pan.

If the dough is baked before fermentation has progressed far enough, the resulting bread has thick cell walls and is decidedly less tender than bread fermented sufficiently. The volume is also smaller. This is because the gluten with the proper length of fermentation becomes more dispersed and tender. If fermentation is carried too far the gluten becomes too soft to retain all the expanding gas bubbles and several cells coalesce, producing thick cell walls and coarse texture. With extreme fermentation the dough smells sour, and a very coarse, heavy, compact bread of small volume and sour taste is obtained.

Prevention of crust formation during fermentation. Drying of the crust may be partially or wholly prevented by covering, keeping in a cabinet with high humidity, or greasing the crust.

A crust formed after the dough is panned gives a dry layer on top that is less elastic.

As a consequence a compact layer of cells is formed in the loaf just below the crust.

Temperature of fermentation. Fermentation is carried out over a wide range of temperature. The evidence indicates that a low temperature is more desirable from the standpoint of flavor and the development of acetylmethylcarbinol. But fermentation is more rapid at high temperatures. Temperatures from 26° to 32°C (79°–90°F) are used. There is more danger at higher temperatures for growth of undesirable organisms which produce disagreeable flavors.

Methods of mixing. *Straight-dough process.* Two processes are used in making bread. In the straight-dough process or quick method all the flour and other ingredients of the bread are mixed together in the dough for the whole fermentation period.

Sponge process. By this method the salt and a part of the flour are omitted during the first part of the fermentation period. Then the remainder of the flour and the salt are added to make a dough, and from this point the manner of mixing and treatment of dough are the same for the two processes. The sponge process is used for some types of bread. It produces a slightly different flavor from the straight-dough process.

Handling of dough. In the laboratory one is constantly impressed by the lack of uniformity, due to the manner of manipulation, in products baked from the same ingredients. Swanson (123) says that it is well known that bread dough must not be squeezed too hard when kneaded just before it is put in the pan. During fermentation the meshwork of gluten has become separated into fine filaments. If kneaded too hard just before panning these filaments are packed together, producing thicker cell walls.

Dunlap (62) also emphasizes this point. After tests he decided that he had punished the dough too hard or used too much pressure in punching it, especially for the last working. He states, "Putting this idea to the test and handling the doughs with a degree of gentleness previously unknown in my method of operation, results were produced incomparably better than anything previously obtained."

Prolonged mixing (44) may destroy the cohesiveness of the gluten. On the other hand, the dough may be mixed sufficiently and in such a manner that its properties are altered sufficiently so that it can be baked after the first fermentation period.

Changes in dough during baking. Baker and Mize (46) baked bread by making the dough the resistance unit between electrodes carrying alternating current. During this period the voltage required to keep a constant wattage flowing, the temperature rise produced in the dough, the rate of oven spring of the dough, the rate of fall of a weight through the dough, and the pressure generated in the dough during baking were determined.

The dough softens during heating until swelling of the starch granules commences at about 58°C (136°F), as shown by the change in rate at which the weight drops through the dough. A slight decrease in temperature rise parallels the swelling of the starch. Destruction of the yeast begins during this period but is not complete until a much higher temperature is reached. The coagulation of gluten occurs from 74°C (165°F) until the end of the baking period. In desirable doughs, expansion ceases during coagulation of the gluten. In undesirable doughs, expansion may be arrested before coagulation of the gluten starts. The thermal expansion of the gases, the gas being driven out of solution, and the increased rate of yeast action cause the oven spring.

Bailey and Munz (45) find the oven expansion to be about 80% of the initial volume when placed in the oven. The expansion is rapid during the first 10 minutes of baking and ceases when the temperature reaches 50–60°C. Oven expansion or spring results from the expansion of gases or vapors.

Greasing of bowl and pans. The bowl in which the dough is allowed to rise should be greased with only a thin film of fat, or it is not necessary to use any. Heavy greasing may produce streaks in the bread. Harrel (145) found that bread baked in ungreased pans had a better volume and oven spring than bread baked in greased pans. This indicates that the dough clings to the sides of the pan during rising, and this adhesion aids in attaining a better volume. But greasing the bottom of the pan expedites removal of the bread.

Size of pan. The volume of the loaf and the shape of cells of the bread depend upon the method of panning and the relation of the amount of dough to the size of the pan.

When the dough (145) is placed on one side of the pan so that it has to turn over in rising, the volume is reduced and the loaf is likely to crack in the center from pressure. The dough should be placed in the middle of the pan and shaped so that it is uniform. Harrel (145) found that, with conditions otherwise standardized, a loaf placed slightly to the side of the pan gave a volume of 2700 cc but placed in the middle of the pan gave a volume of 3230 cc.

Lewis and Whitcomb (151) in their investigations on the "Influence of Size and Shape of Pan on Baking Test" concluded that the purpose for which the pan is intended should govern its shape and size. An experimental bake is a test of the strength of the flour; for this purpose a pan should be used that puts a more severe test upon the flour. Their conclusions follow. "The shape of the pan exerts a marked influence upon the size and quality of the loaf in both strong and weak flours.

"The proof period varies with different types of pans. It does not correspond closely with volume or height of loaf or quality of bread.

"Deeper pans produce taller loaves, but not the larger loaves.

"The deep type of pan produces a smaller loaf of somewhat poorer quality than the shallow type. Hence a flour that will produce a good loaf in a deep pan can be depended upon to perform well in the bake shop where the shallow type of pan is used."

Flavor of bread. Visser't Hooft and de Leeuw (156) have reported that excellent flavor in bread is caused by two factors. One is a blend of the flavors of the various ingredients, and the other is diacetyl, an important flavor constituent of butter and other products. Diacetyl is formed from slow oxidation of acetylmethylcarbinol, which is a byproduct from fermentation of sugar by yeast. Baker et al. (129) divide the origin of bread flavors as follows: the ingredients, fermentation, and baking. They have identified many of the constituents in condensates of the vapors from bread during baking. These include ethyl alcohol, acetaldehyde, fusel oil (isoalcohols), pyruvic aldehyde, diacetyl, furfural, acetic acid, with isoaldehydes, ketones, and esters. Of these furfural, pyruvic aldehyde, diacetyl, and the isoaldehydes were collected only from dough containing sugars. They state that all these substances have strong and suggestive odors. They divide the flavor substances produced by fermentation and baking of bread into volatile, less-volatile, and low-volatile compounds. They also discuss possible ways of retaining in the bread and increasing the desirable flavor ingredients. Bertram (131) and Baker et al. (129) discuss the importance of the browning or Mallaird reaction in color and flavor development of the crust and the former conception that the brown crust color was due to caramelization of sugar and/or dextrins.

The use of soft-wheat flour in bread making. There is a large production of soft-wheat flour in some sections of the United States. Winter wheat, by which is meant wheat planted in the fall, is often called soft wheat. There are two types of winter wheat, one of which produces a soft-wheat flour and the other a hard-wheat flour. The type produced depends upon the place grown and the variety of wheat. Soft wheat is more generally grown in the southeastern states, and soft-wheat flour is used extensively in this area.

Soft-wheat flour (136) can be used in baking bread, but the manipulation required is different from that for strong-wheat flour. The gluten in soft-wheat flour is less colloidal, more dispersed, than in strong-wheat flour. Since fermentation produces greater dispersion of the gluten, which gives greater elasticity and a more tender gluten, the fermentation period is necessarily shorter for soft-wheat flour than for strong-wheat flour. Better results are also obtained if the proportion of yeast is increased. With increased yeast the sugar is usually increased, as it furnishes a quick food supply for the yeast. Soft-wheat flours do not have so high a hydration capacity as strong wheat, so that it is necessary to use a smaller proportion of liquid. A shallow pan gives better results than a deep one.

Roll Mixes

All the ingredients, with the exception of the liquid and the dry yeast, are combined in the roll mix. The dry yeast is in the container with the other ingredients but in a separate package. Garnatz (143) states that roll mixes present no problem except for shelf-life stability. The stability is due primarily to problems associated with deterioration of the yeast, with a detrimental effect on fermentation and flavor. In 1948 (143) pie crust mix and hot roll mix were the leading items in the prepared-mix field, but in 1950 the hot roll mix was in a lower category. Suggested reasons for this decline, listed in the order of probable importance, are: (*a*) the introduction of Brown N' Serve products, (*b*) the fact that the mixes did not save enough time, and (*c*) problems associated with shelf life.

The Staling of Bread

Changes occurring during staling. The changes that take place during the aging of bread which are readily evident to the consumer are: increases in firmness and crumbliness and change in flavor. They are brought about by physicochemical changes occurring as the bread cools and ages. The causes for the changes in firmness and crumbliness are still not well understood. Changes in flavor, in part at least, can be caused by loss of volatile constituents that give distinctive aroma to fresh bread. Moisture loss may occur. However, staling will occur when moisture loss is prevented but redistribution of the moisture within the loaf occurs. The low-moisture, crisp crust at the end of baking gradually takes moisture from the crumb (132, 138, 146), the outer crumb losing moisture more rapidly than the inner crumb. Katz (146) found that the crumb had increased in firmness sufficiently to be called stale within 9–10 hours after baking. Crumbliness lagged, requiring 24 hours to appear.

Methods for determining staleness. Bice and Geddes (132) evaluated some of the most promising methods of measuring changes that occur in bread during staling. These included a modified Farinograph technic, method for measuring crumbliness, crumb compressibility which included crumb softness (deformation under constant load), crumb firmness (load required to produce a given compression), swelling power, and the amount of soluble starch. They discuss these methods in relation to a consumer's subjective rating which may be made unconsciously by integration of many factors. They state that a physical or chemical method can measure, at best, only a few factors that make up the subjective integrated assessment. Since the various staling processes do not take place at the same time, methods that measure differences may not give identical data. They suggest that a study is needed to relate the various objective measurements to the organoleptic ratings made by a trained panel under statistical control. Edelman et al. (139) state that crumb firmness as shown by the Baker Compressimeter and Bloom gelometer reflects the findings of the consumer's preference in bread.

Delaying staling. Increasing the amount of yeast and varying the fermentation time (142) had no effect on staling. On the other hand, development of crumb firmness (139) is said to be delayed by the use of lard as an ingredient, by the use of maximum water absorption to produce bread with not more than 38% moisture, and by obtaining the maximum ratio of pan volume to dough weight. The use of a surface-active ingredient is important in the retarding of staling due to hardening of the crumb.

Reversibility and temperature of staling. If bread is kept at 60°C or above or at a very low temperature the hardening and crumbling of the crumb is very much retarded (146). According to Katz (146), as the temperature drops below 60°C the rate of staling of the bread increases, reaching its maximum at −3°C (27°F). As the temperature is dropped below −3°C the rate of staling decreases until at −22°C bread will stay fresh 30 days, and at −35°C for approximately 70 days. Stale bread when reheated to 60°C acquires the characteristics of fresh bread. This process can be reversed several times or until the bread has lost too large a proportion of water.

Theory of staling. During baking the starch gelatinizes. In the fresh state some starch can be leached from the crumb with cold water. As the bread stales the amount of this soluble starch progressively decreases. The staling, for a long time, was attributed to the amylose fraction of the starch, which becomes irreversibly insoluble. But, as Alsberg (*A Comprehensive Survey of Starch Chemistry,* p. 87, edited by R. P. Walton) has pointed out, retrogradation is irreversible and is brought about slowly, whereas staling is reversible and develops rapidly.

Schoch and French (153, 154) have found that the water-soluble starch extracted from fresh bread crumb is predominantly the amylopectin or branched chain (B-fraction). They find that the amylose (A-fraction) was insolubilized by retrogradation during baking and does not contribute to the staling process. The decrease in soluble starch during staling they attributed to aggregation of areas, forming crystallites, in the branched chain. See Fig. 56. If the stale bread is heated to 50°C or above, the amount of the branched chain fraction that can be extracted is increased. Parallel behavior was observed during aging of a 50% aqueous paste of defatted wheat starch, which substantiates the theory that staling is inherent in the branched fraction of the starch and is not caused by interaction with other bread ingredients. The other ingredients may influence the rate of staling.

Ropy Bread

The so-called rope in bread or ropy bread is *B. mesentericus,* introduced into the bread through the yeast, flour, bread box, mixing bowl, or flour bin. The spores of this bacteria are not destroyed by the heat during baking of the bread. A sticky, gummy material which will pull into threads develops in the center of the loaf 1 to 3 days after baking. In the early stages the center of the loaf may be crumbly and odorless. In later stages the odor is foul. The optimum temperature (133) for the development of rope is close to 40°C. Hence, it always develops during very hot weather or when the bread is kept in a warm place. It has been found (152) that, the greater the contamination, *e.g.,* when the number of bacteria per gram for flour was raised from 6 to 1300, the more rapid was the development of rope.

Materials that render the dough slightly more acid than normal are effective in preventing rope development. The acidity should be *p*H 5 or lower.

Some acids or acid substances do not interfere with yeast growth. The following can be used: 1 part of 100-grain vinegar to each 100 parts of flour; 2 grams of cream of tartar to 1 quart of flour; 0.5 pound or less of monocalcium phosphate per 100 pounds of flour; lactic acid; and sodium or calcium propionates. The propionates are effective without lowering the *p*H.

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BREAD

Experiment 48.

To determine the best proportion of water for the kind or grade of flour that is to be used in making bread.

Brand of flour used:
Recipe:

Ingredients	Approximate measure	Large dough or large loaf, grams	Small dough or small loaf, grams,
Flour	3⅛ cups	350.0	100.0
Yeast	¾ cake	10.5	3.0
Sugar	¾ tablespoon	10.5	3.0
Salt	1½ teaspoons	7.0	1.5
Fat	½ tablespoon	6.5	0.0

Fermentation	
First punch	105 minutes 28°–30°C (82.4°–86°F)
Second punch	50 minutes
Pan	25 minutes after second punch
Proof	55 minutes
Bake	35 minutes 220°C (428°F)

Use the large or small dough for baking. The fermentation time for the large dough or large loaf is 265 minutes or nearly 4½ hours. That for the small dough or small loaf is 290 minutes or nearly 5 hours. If a shorter fermentation period is desired increase the amount of yeast used as follows:

Amount of yeast	Period of fermentation	Temperature
1 cake of yeast to 1½ cups liquid	4 hours 2 hours 1st rising 1 hour 2nd rising 1 hour in pans	80
2 cakes of yeast to 1½ cups liquid	3 hours 1½ hours 1st rising 45 minutes 2nd rising 45 minutes in pans	80
3 cakes of yeast to 1½ cups liquid	2 hours 10 minutes 1 hour 1st rising 15 minutes 2nd rising 35 minutes in pans	80
4 cakes of yeast to 1½ cups liquid	1 hour 25 minutes 1st rising 5 minutes 2nd rising 30 minutes in pans	80

Determine the temperature of the water necessary to bring the dough to 28°C. This may be done for the first trial by taking the temperature of the room plus the temperature of the flour and subtracting from 84. The result will be the temperature of water to use, to bring the dough out at 28°C. This will not always bring the temperature of the dough out at 28°C, especially if the temperature of the room is rather low and mixing is continued for some time. To find the temperature of the water to bring the dough out at 30°C, subtract the temperature of the room plus the temperature of the flour from 90.

Sift the flour. Dissolve the sugar and salt in a portion of the water and mix the yeast in another part. Add water and melted fat to the flour, and mix to a smooth dough. If a bread mixer is used, mix until the dough is smooth. Keep a record of the time, and mix other batches of dough for the same length of time. If mixed with a spoon mix until a dough is formed, then knead on a flat surface until smooth. The length of time for kneading depends upon the vigor and rapidity of kneading. It is better to work out a definite method of kneading and count the punches used. Otherwise the amount of kneading will produce variations and it will then be difficult to determine variations due to other causes. Try 300 punches, unless it is found that, owing to method of kneading or other factors, more or less kneading gives better results.

For fermentation place in a container of suitable size, and cover. To obtain a constant temperature in a cooking laboratory the dough may be placed in a covered bowl or pan and set in a dishpan of water, the water being at the desired temperature for fermentation. Add hot water as needed to keep the temperature constant. The dishpan should be covered to avoid drafts over the top of the bread.

An empty refrigerator makes an ideal proofing cabinet, as it is easy to regulate the temperature by a pan of hot water in the bottom, and it is moist so that there is no tendency for a crust to dry. A china closet, a box, or an oven can also be used.

Leave the dough in the container for the punches and punch just sufficiently to bring the dough to the original volume. Count the strokes used for punching and use the same for all the doughs and the same method of making strokes. For panning, turn out on a smooth surface and knead or fold gently into the desired shape. Use no flour to mold as this flour will not be fermented for the same length of time as that in the dough and may leave streaks in the bread.

Prevent a crust from forming while rising and while in the pan. If necessary, moisten the top occasionally with water.

1. Use 55% of water or 192.5 cc.
2. Use 57.5% of water or 201.2 cc.
3. Use 60% of water or 210 cc.
4. Use 62.5% of water or 218.7 cc.
5. Use 65.0% of water or 227.5 cc.

Experiment 49.

To determine the effect of manipulation of the dough upon the volume, the texture, and the tenderness of bread.

A. The extent of mixing and the pressure used in kneading.

1. Use the proportion of water found best under Experiment 48. If this has not been determined, try 60%. Follow directions for mixing given under Experiment 48. Mix 3 times the recipe used. Knead as in Experiment 48.

using 400 punches. Weigh the dough and divide into 3 portions. Put part one in the proofing cabinet to rise. Use the remainder of the dough for 2 and 3.

2. Continue kneading one part of the dough from 49, 1, for 15 to 20 minutes or use 1000 punches. For the rest of the operations duplicate the procedure under 1.

3. Put the third portion of the dough from 49, 1, to rise. When punching after the first fermentation period use more strokes for punching and more pressure. Knead hard just before molding the loaf to put in the baking pan.

B. Method of molding.

Repeat A1, using the regular recipe. When molding the dough for the baking pan pat gently into a long narrow strip that can be rolled for the loaf. Roll around about 2 times and shape and place in pan.

Compare the appearance, volume, texture, and tenderness of the loaves of bread. Compare the shape and direction of cells in the baked loaves. Does rolling compress a part of the dough so that some cells are more compressed than others?

Experiment 50.

To determine the effect of fermentation on the volume, the texture, and the tenderness of bread.

Mix 2 times the recipe used. Follow directions given under Experiment 48, using the proportion of water that gave the best loaf. If this has not been determined use 60%. After kneading, weigh and then divide into 2 parts. Mold and shape one loaf, and place directly in the baking pan. Let rise to the desired height and then bake. The second half of the dough should be fermented and punched in the regular way before molding and baking. Compare the two loaves for volume, appearance, color of crumb, texture, and tenderness.

Experiment 51.

To determine the effect of changing the proportion of ingredients.

Mix in the usual way, ferment, and bake the usual time.

A. Salt.

1. Repeat Experiment 48, using the best proportion of water for a control loaf.
2. Increase the salt to 8 grams.
3. Decrease the salt to 2.6 grams.

B. Sugar.

1. Double the sugar in the recipe. Use A1 for a control.
2. Omit the sugar in the recipe.

C. Fat.

1. Double the fat in the recipe. Use A1 for a control.
2. Treble the fat in the recipe.

Compare the effect on volume, appearance, texture, and tenderness of bread of changing the proportion of ingredients.

CHAPTER
13

Batters and Doughs

LEAVENING AGENTS

Leavening is increasing the surface area of a dough by creating or occluding within it myriads of gas bubbles. The created gas is mainly CO_2 produced by yeast or by chemical means and the production of steam from water. The occluded gas is air. The expansion of these gases during baking increases the volume of the product and gives a desirable porous structure.

Air. Air may be incorporated into a batter through an egg-white foam, by creamed fat and sugar, and to a lesser extent by aerating the flour through sifting and by beating the batter. For each degree rise in temperature a gas expands $^{1}/_{273}$ of its volume. If a batter contains 100 cc of air, the air will increase to about 137 cc when heated from 0° to 100°C. Such batters often more than double their volume in baking. Thus it is obvious that gas must be generated in the batter in addition to occluded gas to obtain this expansion.

Air plays a role in leavening beyond its expansion in the baked product. Dunn and White (24) found that poundcake from which the air is evacuated does not increase in volume during baking. Yet, if the air is not evacuated, half of the expansion during baking is attributed to steam. They conclude that the water evaporates into the small air cells; then expansion of this water vapor and the air occurs. Hood et al. (37) also find that if the air is completely evacuated there is no volume increase during baking of air-steam leavened cakes.

Steam. One volume of water forms about 1600 volumes of water vapor, so that steam has great leavening ability, even in products containing as little water as pastry. Angel cake contains a large quantity of air, yet Barmore (9) has calculated that steam brings about 2–3 times the expansion in baking angel cake as the incorporated air.

The effectiveness of steam as a leavening agent in cake varied with the type of fat used and whether CO_2 from baking powder is present. Thus steam (37) is the major leavening in air-steam leavened cakes, but is less important in the air-steam-CO_2 leavened cakes. The relative increase in volume of cakes from the different leavening agents follows:

TYPE OF FAT IN CAKE	BUTTER %	OIL %	HYDROGENATED LARD %
Air-steam leavened cakes			
Increase from air	19.8	11.4	25.0
Increase from steam	80.2	88.6	75.0
Air-steam-CO_2 leavened cakes			
Increase from air	8.0	5.6	6.7
Increase from steam	32.3	44.1	20.7
Increase from CO_2	59.7	50.3	73.1

Soda. Sodium hydrogen carbonate or soda may be used for a leavening agent. When heated it gives off gas as follows:

$$2NaHCO_3 + \text{heat} \rightarrow Na_2CO_3 + H_2O + CO_2$$

The residue, sodium carbonate, gives a disagreeable taste and produces a yellow color in the baked product. For this reason some substance is used with soda that combines with it to give an end product that does not affect the flavor or color of the food so decidedly as Na_2CO_3.

HCl and $NaHCO_3$. The following reaction is typical of baking-powder reactions in that an acid substance is combined with the soda to produce the gas. According to Hart (35), the first patent for a baking powder, taken by Dr. Whiting in 1837 in England, was for the formula given below. In the baking powders of today an acid salt, in powder form, replaces the hydrochloric acid of this formula.

$$HCl + NaHCO_3 \rightarrow H_2O + CO_2 + NaCl$$

Baking ammonia. Baking ammonia (ammonium hydrogen carbonate) has been used for years in baked products and is still used for some goods. When heated it breaks up to form ammonia, water, and CO_2. Since two gases are produced it is an efficient leavening agent. The chief objection to its use is that

$$NH_4HCO_3 + \text{heat} \rightarrow NH_3 + H_2O + CO_2$$

unless all the NH_4HCO_3 is broken up and all the ammonia gas driven off, the taste of NH_4HCO_3 and NH_3 and the odor of NH_3 remain in the baked product. For this reason it is used in baked products, like cookies and cream puffs, that are small and have thin walls.

Sour milk. The use of sour milk and soda to produce CO_2 in baked products antedates the use of baking powder. As the acidity of the milk varies with its age and degree of sourness, the amount of soda needed to neutralize the acidity will also vary. For this reason a stated amount of soda in a given recipe is usually not the correct proportion for the milk used. An average amount for ordinary sour milk is ½ teaspoon of soda per cup of sour milk. This proportion produces gas equivalent to the amount produced by 2 teaspoons of baking powder. As this does not always produce as porous a texture as is desired, some baking powder may also be added. It is preferable from the color, the flavor, and the nutritive values to use too little soda to neutralize the acid in the milk, rather than an excess.

Molasses. Cooking molasses and sorghum, like sour milk, vary in acidity, so that the amount of soda required to neutralize the acid varies. It has been found (22) that some require ½ teaspoon of soda per cup, others ¾, and some 1 teaspoon. Because the flavor of molasses masks the flavor caused by the excess soda an excess of soda can be used with molasses with less detrimental results to flavor than with sour milk. Sorghum is usually less acid, hence requires less soda for neutralization, than molasses.

Fruit juice and fruit. Fruit juice and soda can be used to produce CO_2 in a batter. In fact the acid of cut-up fruit in cookies will combine with soda to produce some CO_2. But from the standpoint of flavor it is well to omit the soda.

Honey and corn sirup. The acidity of honey (22) requires from ½ to 1/12 teaspoon of soda per cup of honey for neutralization. The acidity of the corn sirup is much lower than that of the honey. Because of the action of alkalies on the dextrose of honey and corn sirup and on the levulose of honey, it is better practice to omit soda with these products.

Cream of tartar. Cream of tartar, an acid salt, combines with soda to form CO_2 gas. It was used extensively before baking powders became common. Many recipes still call for cream of tartar and soda for the leavening agent, and many of them specify equal amounts of these two ingredients. As the weight of a teaspoon of soda or of cream of tartar is practically the same, an excess of soda is left in the baking mixture when equal measures of the two are used, for by weight 188 parts of cream of tartar combine with 84 parts of soda to form 18 parts of water, 44 parts of CO_2 and 210 parts of sodium potassium tartrate. These proportions by measure are approximately 2¼ teaspoons of cream of tartar to a teaspoon of soda.

$$\underset{\substack{\text{Potassium tartrate}\\\text{or cream of tartar}}}{KHC_4H_4O_6} + \underset{\text{Soda}}{NaHCO_3} \rightarrow \underset{\substack{\text{Sodium potassium}\\\text{tartrate or}\\\text{Rochelle salts}}}{NaKC_4H_4O_6} + \underset{\text{Water}}{H_2O} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{CO_2}$$

Baking Powder

Hart (35) states that baking powder was first used in England about 1830. It was made of "pearlash and alum, and later of sesquicarbonate of ammonia." When crystalline substances were mixed with soda, a wider use was insured for baking powder, for with the dry salts, reactions of the baking powder did not take place until it was moistened, and the alkaline and acid substances could be kept in the same container.

The ideal baking powder. Hart states, "From the standpoint of the consumer, the ideal baking powder (*a*) gives the most gas for the least volume and weight of powder; (*b*) gives the gas slowly when cold and increasingly in the cooking dough, so the dough may be mixed cold and left standing several hours; begins to generate gas in quantity in the oven and ceases to generate when it would rupture the crumb; (*c*) leaves a tasteless and absolutely harmless residue in the bread; (*d*) is cheap; (*e*) keeps well. The chemicals should not react on one another in the can and thus lose strength."

Definition and yield. A standard of identity for baking powder has not been established under the Federal Food, Drug, and Cosmetic Act of 1938. The following advisory definition and standard issued under the former Food and Drug Act of 1906 is followed as an enforcement guide (27*b*).

"*Baking powder.* The leavening agent produced by the mixing of an acid-reacting material and sodium bicarbonate, with or without starch of flour. It yields not less than 12 percent of available carbon dioxide.

The acid-reacting materials in baking powder are: (1) Tartaric acid or its acid salts, (2) acid salts of phosphoric acid, (3) compounds of aluminum, or (4) any combination in substantial proportions of the foregoing."

Standardization by starch. Starch is added to baking powder mainly as a standardizing agent. It is added to each type of baking powder in such amounts that 100 grams of the powder yields 14% CO_2. If the amount of CO_2 generated by a definite weight of baking powder were not standardized there would be far greater difficulty than at the present time when one type of powder is substituted for another in a recipe. To some extent the starch absorbs moisture, thus lessening the CO_2 lost in storage, but this is a minor consideration compared with the standardization of the powders.

Types of baking powders. The alkaline ingredient of all baking powders is $NaHCO_3$. The acid ingredient varies, the names of the various types of baking powders referring to the compound used for the acid ingredient. The function of the acid salt is the same, regardless of the type of salt used. It combines with and releases the CO_2 from the $NaHCO_3$. The types of powders are (*a*) tartrate, (*b*) phosphate, (*c*) sulfate, and (*d*) a combination of sulfate and phosphate.

Tartrate powders. The tartrate powders on the market consist of cream of tartar or a combination of cream of tartar and tartaric acid. Tartaric acid is not used alone in baking powders, since, as stated by Hart (35), "Its reaction is rapid and complete in cold water, and its keeping quality correspondingly poor." Cream of tartar reacts more slowly than tartaric acid but keeps and aerates well. Tartaric acid leaves sodium tartarate as a residue.

$$\underset{\text{Tartaric acid}}{H_2C_4H_4O_6} + \underset{\text{Soda}}{2NaHCO_3} \rightarrow \underset{\text{Sodium tartrate}}{Na_2C_4H_4O_6} + \underset{\text{Water}}{2H_2O} + \underset{\text{Carbon dioxide}}{2CO_2}$$

Phosphate powders. Monocalcium phosphate is commonly used in the retail phosphate powders. Sodium pyrophosphate is used principally by bakers and for mixes. Monocalcium phosphate (3*c*) has been improved by developing the anhydrous form.

Bailey (5) gives three equations which represent the reactions that may take place under favorable conditions. He adds that probably equation 3 represents what usually occurs.

$$2CaH_4(PO_4)_2 + 4NaHCO_3 \rightarrow 2CaHPO_4 + 2Na_2HPO_4 + 4CO_2 + 4H_2O \tag{1}$$

$$3CaH_4(PO_4)_2 + 4NaHCO_3 \rightarrow Ca_3(PO_4)_2 + 4NaH_2PO_4 + 4CO_2 + 4H_2O \tag{2}$$

$$3CaH_4(PO_4)_2 + 8NaHCO_3 \rightarrow Ca_3(PO_4)_2 + 4Na_2HPO_4 + 8CO_2 + 8H_2O \tag{3}$$

With sodium acid pyrophosphate Bailey states that there is some question concerning the products of reaction and gives two equations that may represent what occurs:

$$Na_2H_2P_2O_7 + 2NaHCO_3 \rightarrow 2Na_2HPO_4 + 2CO_2 + H_2O$$

and

$$Na_2H_2P_2O_7 + 2NaHCO_3 \rightarrow Na_4P_2O_7 + 2CO_2 + 2H_2O$$

Sulfate powders. Sodium aluminum sulfate is the acid salt used in these powders. There are not many on the market.

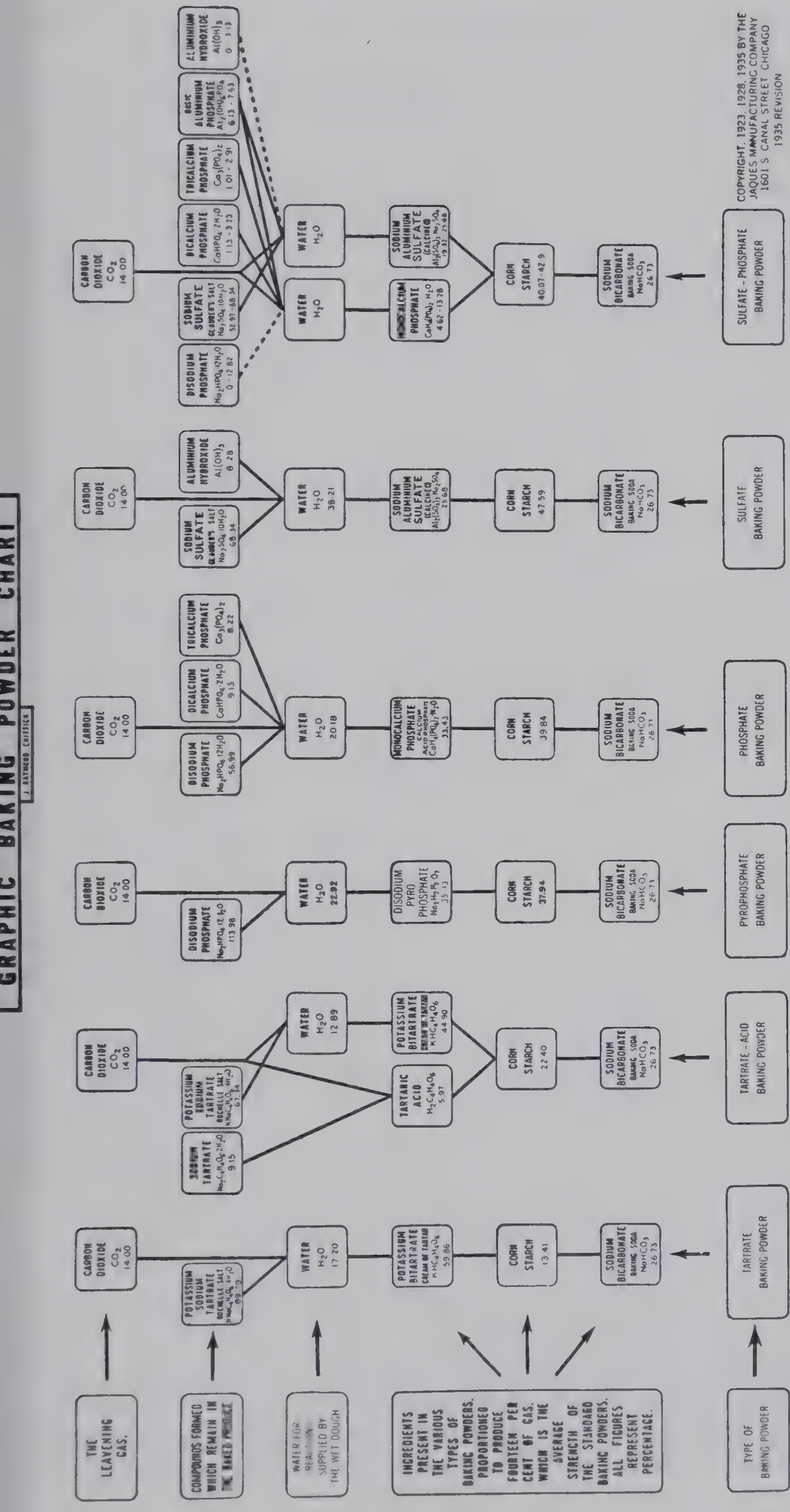
Combination sulfate-phosphate powders. These powders contain two acid salts in varying proportions. The sulfate salt is sodium aluminum sulfate, and the phosphate is monocalcium phosphate. Hart states that sodium aluminum sulfate "has first class keeping quality and has an aerating value about the same as tartaric acid." The reaction of the phosphate salt with soda has been given above. One ingredient of the residue of sulfate powders is aluminum hydroxide. Another is sodium sulfate; in excess, this produces a bitter taste. The sodium aluminum sulfate is first hydrolyzed with water. The sulfuric acid formed then reacts with the sodium hydrogen carbonate. Bailey states, "Besides the reaction of the phosphate and

$$Na_2SO_4Al_2(SO_4)_3 + 6H_2O \rightarrow Na_2SO_4 + 2Al(OH)_3 + 3H_2SO_4$$

$$3H_2SO_4 + 6NaHCO_3 \rightarrow 6CO_2 + 6H_2O + 3Na_2SO_4$$

sodium aluminum sulfate with soda, there is probably an interaction between the two."

The graphic chart (Fig. 58) by Dr. Chittick shows the ingredients present in the various types of baking powders, proportioned to produce 14% of gas. It also shows the compounds formed from the reaction of the


GRAPHIC BAKING POWDER CHART
J. RAYMOND CHITTICK
THE LEAVENING GAS.
COMPOUNDS FORMED WHICH REMAIN IN THE BAKED PRODUCT
WATER FOR REACTION SUPPLIED BY THE WET DOUGH
INGREDIENTS PRESENT IN THE VARIOUS TYPES OF BAKING POWDERS. PROPORTIONED TO PRODUCE FOURTEEN PER CENT OF GAS. WHICH IS THE AVERAGE STRENGTH OF THE STANDARD BAKING POWDERS. ALL FIGURES REPRESENT PERCENTAGE.
TYPE OF BAKING POWDER
CARBON DIOXIDE CO2 14.00
POTASSIUM SODIUM TARTRATE ROCHELLE SALT 89.19
WATER H2O 17.20
POTASSIUM BITARTRATE CREAM OF TARTAR KHC4H4O6 59.86
CORN STARCH 13.41
SODIUM BICARBONATE BAKING SODA NaHCO3 26.73
TARTRATE BAKING POWDER
SODIUM TARTRATE Na2C4H4O6·2H2O 9.15
POTASSIUM SODIUM TARTRATE ROCHELLE SALT 67.34
WATER H2O 12.89
TARTARIC ACID H2C4H4O6 5.97
POTASSIUM BITARTRATE KHC4H4O6 44.90
CORN STARCH 22.40
TARTRATE-ACID BAKING POWDER
DISODIUM PHOSPHATE Na2HPO4·12H2O 113.98
WATER H2O 22.92
DISODIUM PYRO PHOSPHATE Na2H2P2O7 35.13
CORN STARCH 37.94
PYROPHOSPHATE BAKING POWDER
DISODIUM PHOSPHATE Na2HPO4·12H2O 56.99
DICALCIUM PHOSPHATE CaHPO4·2H2O 9.13
TRICALCIUM PHOSPHATE Ca3(PO4)2 8.22
WATER H2O 20.18
MONOCALCIUM PHOSPHATE CALCIUM ACID PHOSPHATE CaH4(PO4)2·H2O 33.43
CORN STARCH 39.84
PHOSPHATE BAKING POWDER
SODIUM SULFATE GLAUBER'S SALT Na2SO4·10H2O 68.34
ALUMINIUM HYDROXIDE Al(OH)3 8.28
WATER H2O 38.21
SODIUM ALUMINIUM SULFATE (CALCINED) Al2(SO4)3·Na2SO4 25.68
CORN STARCH 47.59
SULFATE BAKING POWDER
DISODIUM PHOSPHATE Na2HPO4·12H2O 0-12.82
SODIUM SULFATE GLAUBER'S SALT Na2SO4·10H2O 52.97-68.34
DICALCIUM PHOSPHATE CaHPO4·2H2O 1.13-3.23
TRICALCIUM PHOSPHATE Ca3(PO4)2 1.01-2.91
BASIC ALUMINIUM PHOSPHATE Al2(OH)3PO4 6.13-7.63
ALUMINIUM HYDROXIDE Al(OH)3 0-3.13
WATER H2O
MONOCALCIUM PHOSPHATE CaH4(PO4)2·H2O 4.62-13.28
SODIUM ALUMINIUM SULFATE (CALCINED) Al2(SO4)3·Na2SO4 19.32-25.68
CORN STARCH 40.07-42.9
SULFATE-PHOSPHATE BAKING POWDER
COPYRIGHT, 1923, 1928, 1935 BY THE JAQUES MANUFACTURING COMPANY 1601 S CANAL STREET CHICAGO 1935 REVISION

Courtesy of Dr. Chittick and Jaques Manufacturing Company

FIG. 58. Showing the proportion of ingredients in baking powders to yield 14 per cent of CO_2. In the first square at the bottom of the columns is listed the type of baking powder. Next come soda and cornstarch, which are common ingredients in all powders. In the fourth squares are the acid ingredients and the percentage required to yield 14 per cent of carbon dioxide. The next to the last squares at the top give the residues from the reaction of the baking-powder ingredients; those on the left of the center of each diagram are soluble and those to the right are insoluble in water.

various baking powders and the percentage or possible percentage of these compounds.

Chittick has suggested that baking powders containing the sodium aluminum sulfate salt (sometimes known as aluminum or S.A.S. baking powder) be called sulfate powders, which is an appropriate name. He also suggests that baking powders consisting of a combination of sodium aluminum sulfate and phosphate salts be called sulfate-phosphate baking powder. These changes are shown in the baking-powder chart. Because of the number of times names of types of baking powder are used in the laboratory outline, the author has adopted the abbreviation S.-P. for sulfate-phosphate powders.

Temperature and reaction of baking powders. Baking powders are tested for yield in water. The following yields of baking powder reported by Bailey are by this method, and obviously these conditions are not the same as those in batters and doughs. At room temperature a tartrate baking powder will react completely, a straight phosphate will yield two-thirds of its gas, but heat is required to liberate the remainder, and a combination powder will liberate from one-fifth to one-third of its gas. The baking powders that liberate a larger proportion of CO_2 at room temperature are often referred to as rapid acting; those liberating a small proportion at room temperature are called slow acting. Bailey classes sodium acid pyrophosphate as a slow-acting powder. Barackman (6) states that it may be classed as a rapid-acting powder in water but a slow one in a dough. Sulfate-phosphate is a combination of a rapid- and a slow-acting powder. It can be readily seen that it is possible for some types of powder to lose a larger proportion of gas during mixing than others. For this reason a smaller amount of the slow-acting powders can be used in many baked products.

The amount of carbon dioxide lost from a batter. A smaller proportion of gas is lost from a batter during mixing than from water, owing at least in part to the density and viscosity of the dough mixture. Noble and Halliday (50) show the comparative loss from water and from a simplified dough mixture after mixing for 40 seconds. They have also determined the amount of CO_2 lost when baking powder is beaten for 20 seconds with flour, fat, and water. See Table 33.

Barackman (6) states that for baking purposes the CO_2 from baking powder may be classified in three divisions as follows: (*a*) the amount lost from a dough during mixing and standing; (*b*) the amount causing expansion of the dough, called "bench action" by bakers; (*c*) the amount dissolved and adsorbed and that available from unreacted soda which will be effective as leavening at oven heat. Barackman has determined the CO_2 for these three divisions in biscuits and doughnuts. From the results obtained he concluded that a rapid-acting baking acid caused a larger loss of CO_2 from the dough during mixing, whereas a slow-acting acid has a smaller loss and consequently a greater quantity of available gas left in the dough for baking. Of the gas generated during mixing only 20–30% is

TABLE 33

CO_2 Lost When Baking Powder Is Combined with Water Only, and with Other Ingredients into Batters (*Noble and Halliday*)

Type of baking powder	Average quantity of CO_2 lost when baking powder is mixed for 40 seconds with					Average quantity of CO_2 lost when baking powder is beaten for 20 seconds with flour, fat, and water
	Water	Flour, fat, water	Flour, fat, milk	Flour, fat, sugar, and water		
				4.9% sugar	9.8% sugar	
	% by weight	% by weight	% by weight	% by weight	% by weight	% by weight
Tartrate	10.11	6.77	6.01	6.45	6.78	6.18
Phosphate	9.34	5.56	....	4.71	5.81	4.52
S.-P. 1	5.15	3.25	2.78	2.58	2.60	2.70
S.-P. 2	3.91	2.29	1.76	1.89	2.61	1.27

retained by the doughs. This, plus the gas in the undecomposed soda, is available for leavening in the oven. No appreciable loss of gas occurs after mixing.

TABLE 34

The Percentage of CO_2 Lost from Biscuit Doughs Compared with the Reduction in Specific Volume of Biscuits (*Barackman*)

Acid ingredients	CO_2 available in dough at 2 minutes, %	CO_2 lost after 15 minutes, % of available	Specific volume of biscuits baked immediately	Reduced specific volume due to standing, % loss
Phosphate..........	49	4.0	2.24	8.5
S. A. P. P..........	78	6.5	2.75	9.0
Tartrate............	70	13.0	2.65	11.0
Sulfate phosphate *...	76	6.5	2.41	3.0

* Exception due to effect of acid on colloidal properties of dough.

In Table 34 the specific volume is obtained by dividing the volume of the biscuits by their weight. Barackman's conclusion was that a correlation exists between the CO_2 left in the doughs after mixing and the volume of the baked product. The major portion (70–80%) of the CO_2 generated from baking powders during the mixing of doughs is lost. In Table 34 the reduced specific volume is due to the biscuits being mixed and allowed to stand 15 minutes before cutting and baking. The controls were baked within 2–3 minutes after mixing.

Fineness of division of baking powder. The fineness of division of a baking powder may affect the grain and texture of the baked product. With finely ground powders it seems reasonable to expect that the bubbles of CO_2 produced will be smaller than with coarser baking powders, and that a finer grain will thus result in cakes and other products. Patterson (53) refers to such a result with finely ground baking powders. Sifting the baking powder with the flour aids in mixing it more uniformly throughout the batter or dough, and prevents loss of gas that would occur if it were mixed with the liquid.

Brown spots are often produced on the crust of cookies, biscuits, cakes, and other products when baking powder is used in them. If the baking powder contains soda that is not finely ground, these spots are more likely to occur. The spots do not develop in the thin batters because of the large proportion of liquid, for solution of the soda is thus obtained. The brown spots appear in the product when the baking powder has been mixed only a short time with the dough. With longer mixing the soda is dissolved and the spots do not appear. If doughs are allowed to stand before baking, the spots may not develop or a smaller number may form. Since cakes are usually mixed longer than biscuits and cookies, the spots develop more frequently in cakes when the baking powder is added after the mixing of the batter is partially completed.

The Structure of Batters and Doughs

The texture or structure of the finished product depends partly upon the structure obtained in the batter or dough when it is mixed. The role the flour plays in batter and dough products is the same as in bread, but since the batter or dough may contain different proportions of liquid and other ingredients the structure of the baked product is often unlike that of bread.

The factors that affect the texture of the finished product may be listed as follows: (*a*) the ingredients, (*b*) the proportion of the ingredients, (*c*) the kind and amount of baking powder, (*d*) the extent of mixing, (*e*) the temperature of the ingredients when mixed, and (*f*) the method of mixing or combining ingredients.

Doughs and batters may also be considered in relation to their physical properties. One property of batters and doughs which is intimately connected with their structure, and which can be measured, is viscosity. Viscosity of batters and doughs is important enough to warrant repeating the ten factors listed by Ostwald as causing variation in viscosity, which have already been mentioned in Chapter 1. They are: (*a*) concentration, (*b*) temperature, (*c*) degree of dispersion, (*d*) solvation, (*e*) electrical charge, (*f*) previous thermal treatment, (*g*) previous mechanical treatment, (*h*) the presence or absence of lyophilic colloids, (*i*) the age of the lyophilic sol, and (*j*) the presence of both electrolytes and non-electrolytes.

The ingredients and their proportion. When factors (*a*), (*h*), and (*j*) are combined, we have a formula or a recipe, in other words, the ingredients and their proportion or concentration. Batters and doughs consist of flour and a liquid. Usually some fat and egg are added, though one or the other may be omitted: fat is seldom used in popovers, and baking-powder biscuits contain no egg. The proteins and starch of the flour are hydrophilic systems. When eggs or milk are added their proteins supply other hydrophilic colloids.

As the concentration or the quantity of the different ingredients in the batter is varied, its properties and characteristics vary, in turn influencing the texture of the finished product. A batter with a high concentration of liquid has a greater fluidity; one with a smaller proportion has a greater viscosity. As the proportion of each ingredient is varied, the finished product is altered accordingly, the kind and extent of the alteration depending upon the particular quality imparted to the batter by the ingredient and upon the proportion of it used.

Liquid. The liquid is a solvent for sugar, soluble salts, and proteins. It is through solution in the liquid that the chemical reaction of baking powder is brought about with release of CO_2. It hydrates the flour and egg proteins, giving the flour proteins cohesiveness and increasing extensibility. Its absorption is necessary for the gelatinization of the starch granules. The proportion of liquid influences the degree of hydration of the protein and starch, and thus the characteristics, including the moistness or dryness, of the finished product.

Flour. Flour forms the framework, the backbone, or skeleton of baked products. The gluten forms a continuous network, and the starch granules, which swell to a greater or lesser extent, depending on the proportion of liquid, acquire more or less adhesive qualities and are embedded in the gluten network, somewhat like bricks in mortar. The flour framework is modified by the other ingredients.

Fat. Fat renders a product tender or short. It is not soluble but is adsorbed strongly on the surface of other constituents and forms films at the crumb/gas interface, or it may be emulsified as an oil-in-water or water-in-oil emulsion. If distributed as an oil-in-water emulsion (particularly in cake), because the fat is surrounded it exerts less shortening effect. Fat is one of the major factors in producing a soft, velvety crumb. It adds richness and up to at least 3% of the weight of the flour increases the volume in bread, but, beyond a certain proportion in cakes, the volume is decreased. It has been suggested (see reference 47, Chapter 12) that a semisolid or solid fat tends to prevent the escape of the gas during baking. Creaming fat with sugar is a means of incorporating air, thus increasing the porosity.

Sugar. Sugar adds flavor. In increasing amounts up to the optimum it tends to increase the volume and tenderness of the product to which it is added. Fat is strongly adsorbed by sugar crystals and is thus distributed throughout the batter. Sugar peptizes egg and flour proteins, elevating their coagulation temperature. In increasing amounts it delays attenuation of the gluten, gelatinization of starch, and solution of the baking powder and other salts, so that CO_2 is produced more slowly. If present in large enough quantity so that it is not completely in solution, it may absorb some of the CO_2, thus lessening the amount lost during mixing. Because it is somewhat porous it may be a means of adding more air to the batter.

Egg. Egg adds flavor and more protein for the framework. If the yolk and whites are not separated, the egg tends to decrease the volume and increase the elasticity and rubberiness. The lecithoprotein of the egg yolk has strong emulsifying properties and in batters emulsifies all or a major portion of the oil or melted fat as an oil-in-water emulsion. When the white is separated from the yolk it can be used as a means of incorporating air, thus increasing the volume and tenderness of the product. Well-beaten whole egg can also serve as a means of incorporating air, if added quickly to the batter before the air is lost.

Baking powder. Baking powder in optimum amounts by its production of CO_2 increases the porosity of products, and, by stretching the elastic protein, causes thinner cell walls, more tender products, and products of larger volume. It enormously increases the surface of the batter in contact with a gas. It is possible that ions of salts of the baking powder or their residual salts may modify the hydration capacity of the flour proteins and some ions may tend to peptize some proteins.

The presence of both electrolytes and non-electrolytes. Baking powder, salt, soda, and cream of tartar belong to the group of electrolytes. Salts affect the imbibition of water by gluten and coagulation by heat. Since baking powders contain different acid salts, it is possible that they may affect, in different degrees, the rate of hydration of the gluten and the total amount of water absorbed.

Sugar belongs to the group of non-electrolytes. Its presence in large quantity in a batter affects the structure and also the extent of mechanical treatment needed to obtain a certain type of grain.

Mechanical treatment. Colloidal reactions are not instantaneous but require time for completion. Hence, the extent of mixing, the length of the mixing period, and the interval between mixing and baking are important. Hydration of proteins, solution of electrolytes and non-electrolytes, and other reactions increase with time until the maximum is reached. A batter does not remain static but changes with age, just as baked products change with age or become stale.

The extent of mixing a definite batter or dough may alter its viscosity or fluidity, and the texture of the finished product varies accordingly.

In the laboratory outline an effort is made to control the amount of mixing in most of the batter and dough series by counting the number of strokes used to stir the batter, particularly after the flour is added. This gives more uniform results when mixing is done with a spoon or similar utensil than specifying the time of mixing, for some girls use more than twice as many strokes in a stated time as others. For uniformity all strokes should be made across the bowl, or all should be a stirring motion. If a very large spoon or one with slots is used, it may be necessary to mix with a smaller number of strokes than the ones suggested.

When possible a mechanical mixer with a definite speed is preferable for school work. Here, too, the amount of mixing required depends somewhat upon the size of the mixer and the quantity of material. With large classes it is not always possible to have enough mixers not to delay the class work. Mixing with a spoon has the advantage of being the common method under most home conditions.

There is an amount of mixing, which partially or completely dissolves the sugar, develops the gluten network sufficiently, and distributes the fat throughout the batter, that gives the best flavor and texture to the finished product. The product is tender and the volume is good. This optimum amount of mixing will vary with each recipe, *i.e.,* with the ingredients and their proportion. The kind of flour used is an example, for the optimum amount of mixing is not always the same for bread and pastry flours. It will also vary with the temperature of the ingredients when they are mixed.

The temperature of the ingredients when mixed. The temperature of the ingredients when mixed influences the structure obtained, particularly in cakes and doughnuts. The protein particles of flour imbibe water more rapidly at higher temperatures. Sugar is more soluble with increasing temperature. But perhaps the consistency of the fat and its distribution throughout the batter are most affected by temperature. If the temperature is low a fat is firmer and less plastic. It spreads less readily throughout the other ingredients. The temperature of the other ingredients may be such that fat is rendered more or less plastic; *i.e.,* they may be warmer or colder than the fat. In cake batters, if an oil is used the oil may be partly or wholly emulsified as an oil-in-water emulsion, the flour and egg proteins acting as the emulsifiers and surrounding the spheres of oil. If a fat is melted and added to a cake batter and the temperature of the ingredients is such that they do not harden the fat, a portion or all of the fat may be emulsified as an oil-in-water emulsion and the structure is similar to that produced by oil. This distribution of the oil in a batter as well as adsorption of fat and proteins at interfaces is probably influenced by the electrical charge.

The method of mixing the ingredients. Bingham (11) states, "A pure liquid, at a given temperature and pressure, can have but a single fluidity, but in our study of liquid mixtures we have seen that a mixture of liquids may have an indefinite number of fluidities dependent upon the method of mixing, in other words, upon the structure of the liquid. Since colloidal solutions are always heterogeneous, they always possess structure, and therefore we have this variable always entering into our consideration, whereas heretofore we have given it but scant attention. There is, however, every gradation from a pure liquid, to an incompletely mixed solution, an emulsion, suspension or typical gel."

Methods of mixing and order of combination of ingredients have been important in many of the products that have been studied, *e.g.,* gelatin, emulsions, milk, and egg cookery. The methods of mixing are particularly important in the batter and dough series. In some doughs, like pastry and biscuits, the fat is first blended with the flour, and the liquid is then added; in others the liquid ingredients are mixed and then combined with the dry ingredients. Various methods of mixing cakes will be discussed in more detail later.

A microscopic study of the distribution of the fat by different methods of mixing shows many gradations from the fat distributed in very thin films to that in thick layers. Sometimes the fat or oil is completely emulsified, sometimes only partly. The sugar may be partly dissolved, "an incompletely mixed solution," or completely dissolved. One can see that it is not strange that cakes and other batter products are not always identical with different bakings. Different methods of mixing may give different results, but from the previous discussion one concludes that a person cannot state definitely of a muffin, biscuit, or cake, that its texture is due to the method of mixing alone, for the extent of mixing, the temperature of the ingredients, interfacial reactions, and other factors influence it.

The effect of extent of mixing on the flavor of dough and batter products. The statement that a cake from one half of a batter after the ingredients are barely mixed does not have the same flavor as a cake baked from the other half of the batter after a longer mixing may seem strange at first. But with longer mixing the sugar is better dissolved, and the other ingredients better blended. To prevent repetition in the discussion of specific batter and dough products, flavor is seldom discussed. But from the standpoint of eating quality, flavor is of great importance, and on a score card the author would rate flavor higher than texture, appearance, or tenderness. However, in the dough and batter series good flavor and good texture are closely related. Since good texture is essential for the enjoyment of a product, if the texture is excellent the flavor is also usually rated high. This assumes that the ingredients are of good quality and flavor, and that proportions are good.

Temperatures Attained by Baking Products

The maximum temperature reached in the interior of baked products varies with the altitude. The most extensive data on the interior temperature under variable atmospheric pressures, which represent variable altitudes, are those of Barmore (9) on angel cake. The following data are from his results.

ALTITUDE, ft	BAKING TIME, min	MAXIMUM INTERIOR TEMPERATURE °C
Sea level	45	99.5
5,000	60	95–96
10,000	75	90

Barackman and Bell (7) have reported the temperatures attained within and by the crust of biscuits, bread, and cake (the results of which agree with those of previous investigators), and in addition results with pancakes, waffles, and muffins. In part, they are shown in Fig. 59.

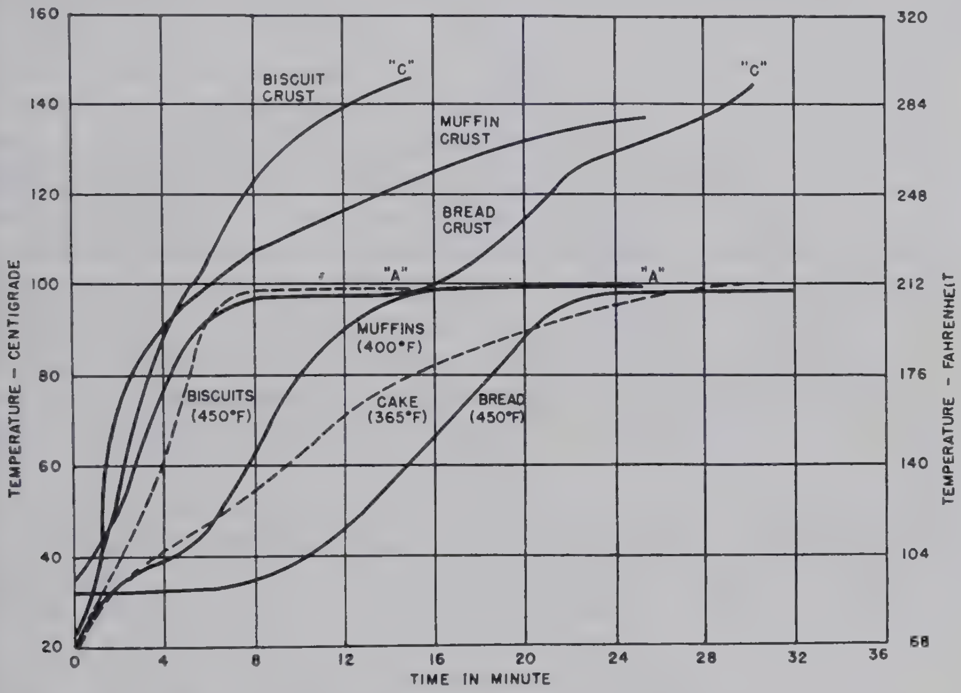


FIG. 59. Temperature of baking products. Temperatures for the *A* curves taken at center of the baking products; those for the *C* curves with thermocouples just within the crusts; for baking-powder biscuit crust—1 mm, muffin side wall—2 mm, bread top crust—2 mm.

Barackman and Bell's results cannot be better stated than in their words. "The temperature attained within most doughs during baking is approximately that of boiling water. The rate at which this temperature is attained is dependent upon the size of the test piece, the oven temperature, possibly the ingredients added, and the character and shape of the pan." The maximum temperature reached varies with the atmospheric pressure.

"Baked products characterized by a soft, spongy crumb do not attain internal temperatures over that of boiling water; only sufficient water is evaporated so that they will retain their cell structure when cooled. This is typical of the production of baking-powder biscuits, bread, cake, muffins, and, by inference, doughnuts.

"Crisp, brittle, short-baked products such as waffles, wafers, crackers, and prepared dog-food biscuits require that their internal temperatures become greater than that of boiling water. The extent to which dehydration of dough colloids is carried is dependent on the baked product under consideration.

"Crusts of baking products rapidly attain a temperature approximately that of boiling water, after which the temperature again rises as dehydration of dough colloids proceeds. The size of the test piece governs the rate of increase in temperature. The shape of the curves thereafter indicates that there is a slowing down of dehydration during caramelization of the crust, so that in a properly browned crust the temperature doesn't exceed 150°C."

Popovers

Popover batter is one of the thinnest commonly baked as a bread product. It is leavened by steam. With the large proportion of liquid used (*a*) the hydration of the gluten particles is so great they do not adhere tenaciously to each other; hence the batter may be beaten for long periods without toughening the baked product to an appreciable extent. (*b*) The starch granules swell to a much greater extent than in a stiffer batter; thus the interior is gel-like in consistency. (*c*) Egg is needed to furnish additional extensible protein to hold the steam formed during baking and to coagulate to form the popover walls. If egg is omitted the popovers do not expand during baking. From 85 to 130 parts of egg to 100 parts of flour by weight (2–3 eggs per cup of flour) are necessary to give a popover of good volume with a large center cavity. The batter may be placed in either hot or cold pans, needs to be baked at a fairly high temperature to form steam rapidly, and should be baked until the exterior is very firm, or the popover will collapse on removal from the oven.

Cream Puffs

Cream puffs contain the same amount of liquid and flour as popovers. In addition they have about a gram of fat for each gram of flour. With this amount of fat the proportion of egg must be about 170 parts by weight to each 100 parts of flour. The function of the egg is twofold: (*a*) to help to form extensible coagulable material for the crust of the puffs and (b) to emulsify and hold the fat in the batter during baking. Reducing the egg causes the emulsion to break and fat oozes from the puff during baking with resulting loss of volume. The quality of the egg also affects the volume of the cream puffs. Watts and Elliott (70) have shown that neither the Chinese fermented nor the treated spray-dried egg whites produce puffs with as large a volume as vacuum-dried or fresh egg whites.

Wheeler (72) states, "Cream puffs are the most unpredictable of baked goods to make. They have long been accepted as the 'hallmark' of the master baker." He emphasizes that the water with the melted fat should be boiling when the flour is added to make the chou paste. The fat is only partially emulsified in the stiff paste produced by cooking the fat, flour, and water. If the paste is overcooked it looks oily and small droplets of fat collect. If some of this paste is baked without the addition of eggs, it never expands in volume and the fat flows from the paste during cooking.

The secret, and therefore the most important factor, in mixing cream puffs in order to obtain good expansion during baking and a good cavity, is to beat the batter while adding the eggs until it is very smooth, with no suggestions of small lumpy spots. Perhaps this is the reason that some directions for mixing cream puffs advise adding the unbeaten eggs one at a time. Incorporating one egg at a time insures thorough blending of the first eggs added. The eggs, however, combine with the batter more easily after they are beaten. Usually, when the egg is first added the batter becomes thinner, but during mixing it becomes increasingly viscous, just as mayonnaise becomes stiffer as large proportions of oil are emulsified. The finished batter should be glossy and very smooth, and if forced through a pastry tube it should retain the imprint of the tube teeth.

The paste should be cool enough not to coagulate the egg proteins when the egg is added. If the paste is cold a much longer time and more energy is required to incorporate the egg in the paste, for the warm dough is less stiff than the cold, and at the higher temperature the surface tension is lower so that the emulsion forms more readily. Steam is the leavening agent, and the expansion due to steam formation produces the cavity in the puff. If the proportion of water drops below a certain level, the tendency for the emulsion to break is increased, with a resulting puff of poor shape and small volume.

Sometimes after the egg is added the batter remains so thin that it spreads when placed on the baking sheet and bakes in a nearly perfect half sphere, with no bottom. The emulsion forms for no fat escapes from the puff during baking, but the batter fails to become viscous. Students who obtain this result have so far been unable to reproduce it.

The puffs, like the popovers, must be baked until very firm to the touch or they will collapse after removal from the oven. A high baking temperature 220–240°C appears to be best. After the puffs begin to brown the temperature can be lowered to reduce the danger of burning and to help dry the puffs. The batter can be refrigerated before use if put in a bowl and covered to prevent evaporation.

Griddle Cakes

Griddle cakes are made of wheat flour, a combination of cereal flours, or/and potato flour, a liquid, salt, and a leavening agent. They may or may not contain egg, fat, and sugar. In a griddle mix all the necessary ingredients are combined except the liquid. The proportion of flour can be varied to produce a thin or a thick griddle cake. Griddle cakes can be used to show the effect of electrolytes and increased gas production upon the stiffness of the batter and the baked griddle cake. For example, if the flour and liquid are kept constant ($1\frac{1}{3}$ cups to 1 cup liquid) and the baking powder is progressively increased from none to 4–6 teaspoons, the batter becomes increasingly stiffer, the baked griddle cakes less moist, more porous, more tender, and of larger volume. The type of baking powder does not make as much difference in volume as might be expected, unless the batter has to stand a long time before cooking. Then a slow-acting powder is preferable.

If colored oil or melted fat is used in griddle cakes and waffles the distribution of the fat can be easily seen. It is dispersed in the uncooked batter as small spheres visible without the aid of a microscope. With the concentration of fat used in these fairly thin batters, this dispersion occurs by stirring the melted fat or oil into the batter and is the same whether the fat is added first or last.

Waffles

Waffles may contain the same ingredients as griddle cakes, though egg is never omitted as it sometimes is in griddle cakes. The proportion of flour may vary from 1 to $1\frac{1}{2}$ cups or more per cup of liquid, depending on the type of waffle desired and the proportion of other ingredients. Because of the air in the beaten egg or egg white they require less baking powder than griddle cakes.

In mixing waffles the eg whites may be beaten stiff and folded into the batter or the whole egg may be beaten until foamy and added to the batter. The former method generally gives the better results. The stiffer the batter the shorter the mixing period should be, if tender waffles are desired.

For any given batter, crispness is obtained by baking the waffle a sufficient length of time. Increasing the fat does not increase the crispness. Increasing sugar, in dessert waffles, gives a crisp waffle, somewhat like a sugar cookie. Waffles with high proportions of sugar may become too brown before they are baked sufficiently. The baking temperature can be lowered for these waffles. Waffles containing a large proportion of sugar are often limp when first taken from the iron, but if they have been baked long enough, they become crisp in a short time.

Muffins

The proportion of flour and liquid in muffins is such that the gluten becomes readily attenuated with slight mixing. The amount of fat and sugar added to muffins is usually not great enough to appreciably prevent this development of the gluten. Thus, to produce tender muffins, the amount of mixing of the batter is very important. Soft-wheat flour produces more tender muffins than hard-wheat ones under the same conditions.

When the egg is not beaten sufficiently to blend easily with the milk or is not beaten after combining with the milk a less desirable muffin, which is tougher and has a rather waxy texture with thick cell walls, is obtained. This occurs even when the muffins are only slightly mixed.

Effect of extent of mixing on texture and appearance. With just enough mixing barely to blend the dry and liquid ingredients, 25 strokes being about the optimum amount, the batter breaks and separates easily when lifted with the spoon, is somewhat lumpy and not smooth in appearance. The top is usually slightly rounded and slightly rough with cauliflower-like bumps. It browns well and has a slight sheen or shiny appearance. The volume of the muffin is good, its cells rather medium and uniform in size, and its cell walls of medium thickness. The muffin is tender. See Fig. 60, muffin 1.

When the mixing of the batter is continued beyond the optimum amount, the appearance of the batter gradually changes, becoming smoother and less lumpy. It flows more readily and as it falls from the spoon forms long ribbon-like strands. The volume of the batter decreases. The baked muffins change in appearance, texture, tenderness, and volume with longer mixing. See muffins 2 and 3, Fig. 60. The top of the muffin is less rounded and may come to a sharp point or peak. Its crust is smoother, browns less readily, and becomes duller in appearance with less sheen. The volume is smaller, the muffins less tender. Up through the center of the muffins are found long holes, called tunnels, that end just below the point at the top. Large holes are often found in muffins and cakes, caused by large air or gas pockets, but tunnels are long and rather narrow. Although the tunnels become more numerous with longer mixing the texture between the tunnels is more compact. With extremely long mixing, and particularly with phosphate and tartrate powders, the batter becomes runny, the texture of the muffin soggy, the volume small, with few tunnels, the top rather flat and very dull and smooth in appearance. See muffin 4, Fig. 60.

Tunnels. Tunnels usually start at the bottom of the muffin and converge near the center at the top. They are formed from expansion of gas in the dough. Part of this gas is from steam, for if one watches the baking of muffins through a glass oven door, occasional small jets of steam may be seen to escape from muffins that have been stirred sufficiently so that tunnels develop. With thin batters like popovers, or doughs like baking-powder biscuits, tunnels do not develop. When the batter contains the proportion of water that results in a very sticky gluten, and the gluten is attenuated to the point at which it is tenacious and somewhat elastic like rubber, the batter drips from the spoon into the muffin pan somewhat as shown in Fig. 61 at *A*. The gluten strands of the batter are stretched toward the point in contact with the spoon. The manner or direction in which the tunnels form is partially dependent upon the way in which the gluten strands are stretched in mixing and in placing the batter in the pans. In the baked muffins the tunnels may form as shown in the cross-section diagram at *B*. When the batter from the end of the spoon falls near the edge of the muffin pan the tunnels may converge as shown in *C*, Fig. 61.

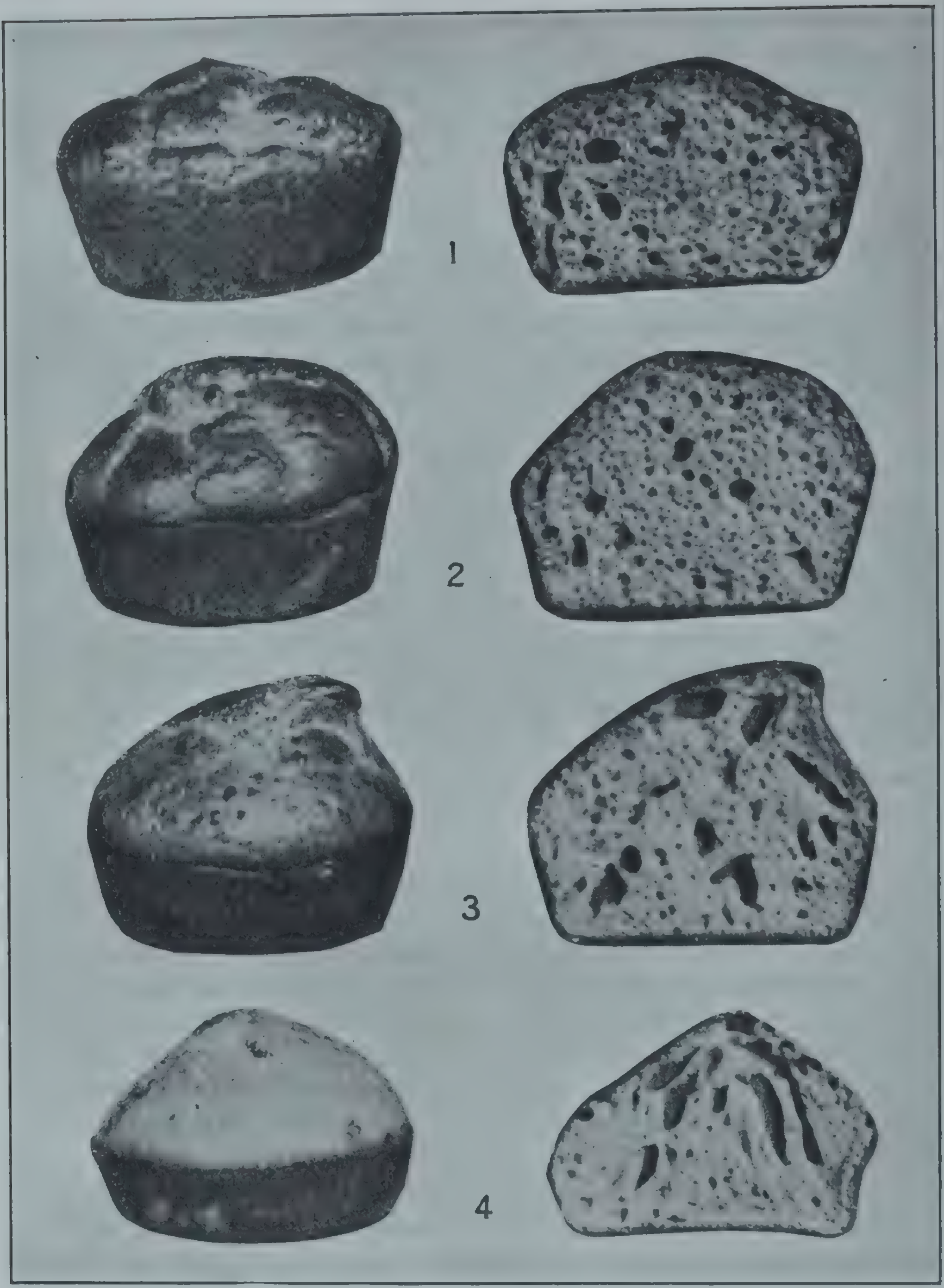


Fig. 60. Muffins. Showing effect on texture, volume, and shape when the extent of mixing is varied and a tartrate baking powder is used. Experiment (55A, 1). Approximately ⅛ of the batter, 60 grams removed after mixing,

1. 30 strokes.
2. 60 strokes.
3. 100 strokes.
4. 300 strokes.

Two other factors that influence the formation of tunnels, though their effect is not always consistent, are depth of the batter and the baking temperature. When the batter is mixed just to the verge of tunnel formation, the deeper the batter in the pan the more likely are tunnels to appear. The temperature is still more variable in its effects than some of the other factors, but tunnels have been observed in portions of a batter baked at higher temperatures, when other portions baked at lower temperatures did not have them or had fewer.

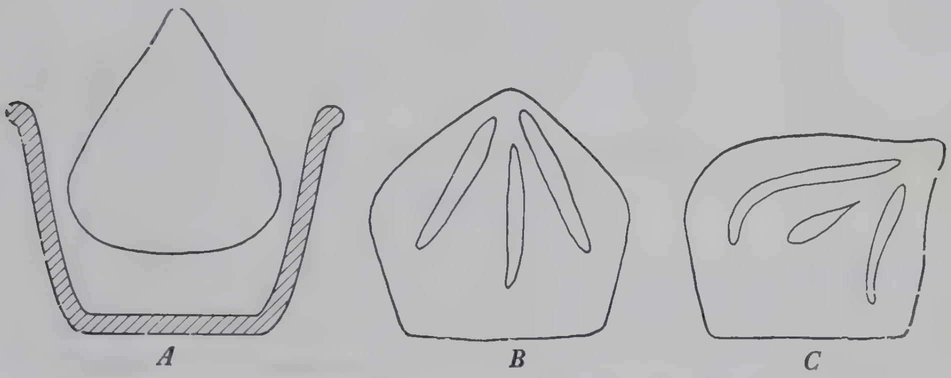


FIG. 61. *A*. Cross section of muffin batter that has been mixed until the gluten is well developed, being dropped from a spoon into a muffin pan.
B. Direction of tunnels in baked muffin.
C. Direction of tunnels when the point of dough falls to one side of the pan.

Varying the proportion of ingredients. Too large a proportion of flour or too little liquid increases the tendency to form tunnels, even with a small amount of mixing. Increasing either or both the sugar and fat retards gluten development, the effect being proportional to the amount added. When the egg is omitted there is less tendency for tunnels to form although the color and flavor are no longer characteristic of muffins. Increasing the egg gives a tougher, more rubbery, elastic muffin.

Baking powder. When equal weights of the three types of baking powders are used under standardized conditions the sulfate-phosphate gives a larger volume, particularly if the muffins are overmixed. In addition the changes brought about when muffin batters are overmixed are slower with the sulfate-phosphate powder. Increasing the quantity of baking powder gives a muffin with larger volume and more porous structure, more tender, and with less tendency for tunnel formation. The batter becomes smoother, more tenacious, and more compact with long mixing. That the volume is less can be observed when 60 grams of the batter are weighed into the baking cup. This shrink in volume is more noticeable with phosphate and tartrate baking powders than with the sulfate-phosphate ones. If the baking powder is omitted during the early part of the mixing, these changes occur more slowly.

The pans. Greasing the sides of the muffin pans lightly or not at all aids expansion of the dough in baking, as the dough can cling more tenaciously to the sides of the tin: greasing the bottom of the pan expedites the removal of the muffins.

Standing before baking. All muffins and nut breads made with baking powder, but particularly those made with rapid-acting powders, should be mixed quickly and put into the muffin tins as quickly as possible after mixing. This lessens the amount of gas lost. They can stand in the muffin tins for some time before baking, because the dough is stiff and viscous and, if not cut across or through, most of the gas is retained.

The palatability of bran muffins can be improved by soaking the bran in warm milk before the flour and other ingredients are added, or the muffins may be allowed to stand for some time after mixing and before baking so that the cellulose of the bran becomes better hydrated and thus softer.

Biscuits

Since hydration capacity of different flours varies, it is necessary to find the amount of liquid for the various brands and grades of flour. The same brand of flour in different sections of the United States is not always from the same kind of wheat. For example, an all-purpose Gold Medal flour in Iowa is from hard wheat, whereas in Alabama or Mississippi it is from soft wheat.

Distribution of fat. Fats are not melted, and either oil or fat is added directly to the flour. If a colored fat is used it can be seen readily that the fat is distributed in layers or pools and absorbed on the flour particles. In biscuit dough, with its small proportion of liquid and no egg, there seems to be little tendency for the fat to form an oil-in-water emulsion. Fat is added to biscuits to give shortness.

Method of combining ingredients for biscuits. In biscuits, a different method of mixing is used from those heretofore considered in the batter and dough series. The fat is added to the flour and blended in some manner: a fine-wired fat blender, a fork, or fingers to keep the fat-flour mixture light. Mixing is not continued until the fat-flour mixture is soggy or packed. The proportion of liquid to flour is smaller than in any product in the batter and dough series. Thus the starch cannot be gelatinized to the extent during baking as occurs in popovers and muffins. Enough water is absorbed during mixing to form gluten and to put biscuits in the group in which tenderness of the product is decreased with overmixing of the dough. Soft-wheat flours because of their smaller protein content produce tenderer biscuits than hard-wheat flours under otherwise standard conditions. Kneading or carefully folding over and rolling tends to develop sheets or layers. With a fine texture this is considered desirable. The crust of biscuits is less crisp with longer mixing or when they are kneaded. Those who prefer a very crisp crust may like dropped biscuits better than kneaded ones.

Calcium acid phosphate and effect of baking powder. The addition of calcium acid phosphate to soft-wheat flours improves their quality for biscuit. Alexander (1) states that phosphate is generally added in most districts in the South. The calcium hydrogen phosphate is acid in reaction. The addition of 0.5% of calcium acid phosphate improves the dough quality (1), biscuit volume, crumb, texture, and color of soft-wheat flours. Logue and Ranker (42) have reported similar results.

Smith and Bailey (62) have reported "The Effect of Chemical Leavening Agents on the Properties of Bread." Their conclusions, in part, for the biscuits and their experimental work follow. "Gluten properties, including elasticity and hydration capacity, are affected by baking powder, and by the residual salts resulting from the chemical reaction of baking powder ingredients.

"Disodium phosphate, the residual salt resulting from the reaction of monosodium phosphate baking powder, affects gluten more than the residues from other types of baking powders."

Loss of thiamine in baking. The loss of thiamine in baking biscuits was considered in Chapter 12 under vitamins. After the thiamine content of flour is enriched, it seems wasteful to use it in such a manner that a large proportion of thiamine will be destroyed in baking. Thiamine is affected adversely by increasing alkalinity. Stamberg and Bailey (63) have shown that of the common ingredients in batters and doughs the baking powder alone appreciably alters the *p*H. Furthermore the elevation of *p*H is in direct relationship to additional increments of baking powder. This suggests using as small a proportion of baking powder as possible. It has also been shown (63) that using dry milk solids (under standardized conditions) at levels of 8, 15, 20, 25, and 30% resulted in batters with *p*H values of 7.70, 7.41, 7.56, 7.31, and 7.29, respectively.

Several studies (8, 13, 73) have shown that thiamine destruction in baking is closely related to the *p*H of the biscuits. Barackman (8) states that about 85% of the thiamine is retained in the baking process if the *p*H of the baked product is *p*H 7.1 or lower. Biscuits rolled to ¼ inch in thickness lost more thiamine than those rolled ⅜ inch. If milk (8, 13, 63, 73) replaces the water more thiamine is retained.

Cakes, Baking

Cake recipes are legion in number, but the underlying principles for making cakes containing a fat are similar, though some variation must be made for different recipes, depending upon the particular ingredients and their proportion.

Cakes containing fat may be divided into two classes: first, the pound-cake type, based on the old recipe, which is 1 pound each of butter, sugar, eggs, and flour, and in which no baking powder or soda is used, the lightness of the cake depending upon the expansion of moisture from the eggs and butter and the air incorporated in creaming and in the beaten eggs;

second, the cup- or layer-cake types that contain rather small percentages of fat and sugar, in which the lightness depends largely upon added baking powder. Between these rich and lean types are many intermediary formulas.

Pans. The cake tends to expand to a better volume if the sides of the cake pans are not greased. A piece of wax or other suitable paper, cut to fit the bottom of the pan and greased on the side of the paper next to the batter, facilitates removal of the cake from the pan. The depth of the batter in the pan also influences the texture of the cake, so that if a finer, more velvety texture is desired, the size of the pan should be such that the batter is at least 1 to 1¼ inches in depth. Charley (19) takes exception to this statement and finds that in general the size and shape of the pan have no effect upon cake texture.

A factor that affects the texture of the cake more than might be expected is the slope of the sides of the pan, a straighter side resulting in a better texture.

Charley (18) determined the effect of using pans of different materials upon the rate of baking, the cake volume, and crumb quality. The cakes baked in the faster-baking pans had larger volume and better crumb quality than those baked in slower-baking pans. The faster-metal baking pans were dark in color and/or dull. The steel, japanned iron, anodized aluminum, and sheet iron were significantly faster baking than the bright aluminum, tinned iron, stainless steel, or copper pans. Cakes baked in glass required a longer baking period than those baked in steel pans of the same size and shape. The oven temperature was 185°C.

Preheated or cold ovens. Peet and Lowe (54) baked formula I, Table 36, p. 489, from a cold and a preheated start in 3 electric, 2 gas, and 1 kerosene ranges. The 12 cakes were mixed on an Institutional Hobart mixer by taking 6 times the formula. Equal amounts of batter were weighed into the 8-inch square pans immediately after mixing. The batter baked in the preheated ovens stood while that started in the cold ovens was baking. Since a sulfate-phosphate baking powder was used, it was thought the standing was less serious for the tests than to use different mixes. All the ovens were set to maintain a temperature of 185°C, once this temperature was reached. The cakes started in the preheated ovens were judged superior in all palatability factors to those started in cold ovens. No significant palatability differences were detected in cakes baked in different ranges. The volume of the cakes baked in different ranges did vary significantly, but the starting oven temperature caused no significant difference in the volume of cakes baked in a given range. The texture of the cakes baked from a cold start resembled that of cakes baked at lower temperatures in Stone's study (65).

What happens during baking. Carlin (15) used a heating stage on a specially equipped microscope so that he could observe the cake batter during baking. During baking the fat, part of which has surrounded the air bubbles, melts and releases the suspended air to the batter. There is movement of these air bubbles, which is violent near the end of the baking period. The CO_2 produced by the baking powder does not form new gas bubbles, but finds its way into and enlarges the air bubbles. Thus the number of air bubbles in the batter is important in relation to cake texture.

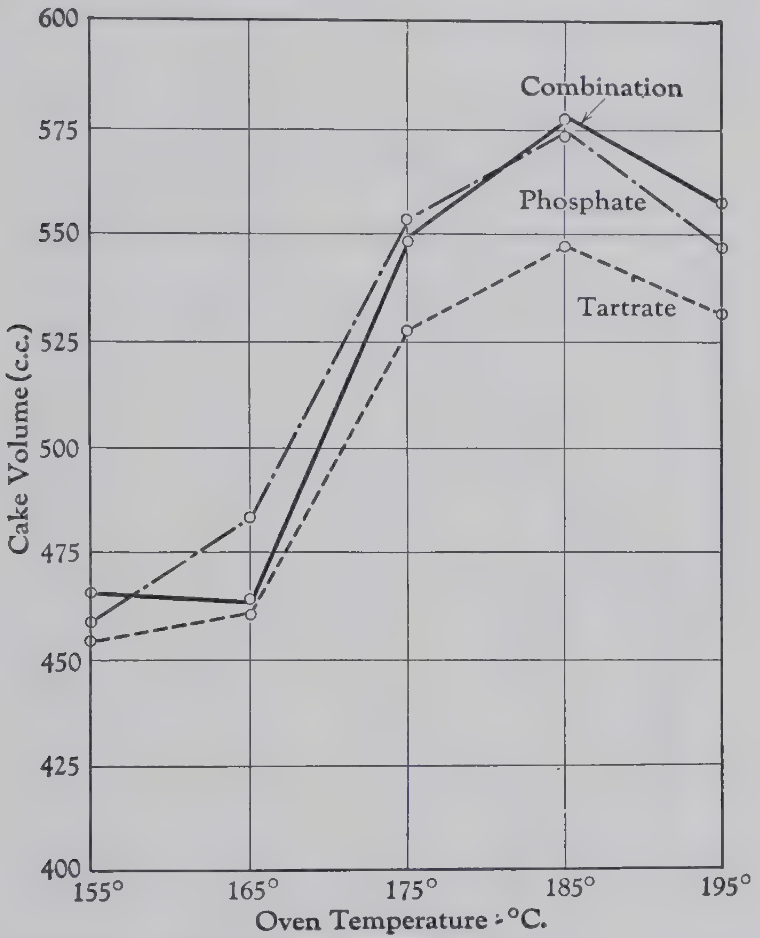


FIG. 62. The effect of baking temperature on the volume of plain cake, when three types of baking powder were used, sulfate-phosphate (combination), tartrate, and phosphate (*Stone*).

The starch gelatinizes enough so that the cross pattern of the granules disappears. The flour and egg proteins are coagulated.

Temperature for baking. Since the gas bubbles agitate the batter during baking, the rate at which the batter is baked affects the volume and texture of the cake. Each cake formula has its optimum baking rate. These temperatures may vary widely from steaming fruit cake at 100°C to baking at 210°C or higher.

Stone (65) found that the optimum baking temperature, for both volume and palatability factors, for the three types of baking powders, when used in formula I, Table 36, was 185°C. See Figs. 62 and 63. For a given baking powder the cake batter was divided into 5 equal parts, 1 part being baked at each of the oven temperatures used. The cakes baked at the lowest temperature had the thickest cell walls, coarsest, and harshest texture. At the lowest temperature, more than the optimum amount of gas escaped and more than the optimum agitation occurred within the batter before coagulation of the proteins started. Beyond the optimum temperature, the volume was smaller because the crust formed too rapidly, although the texture was good.

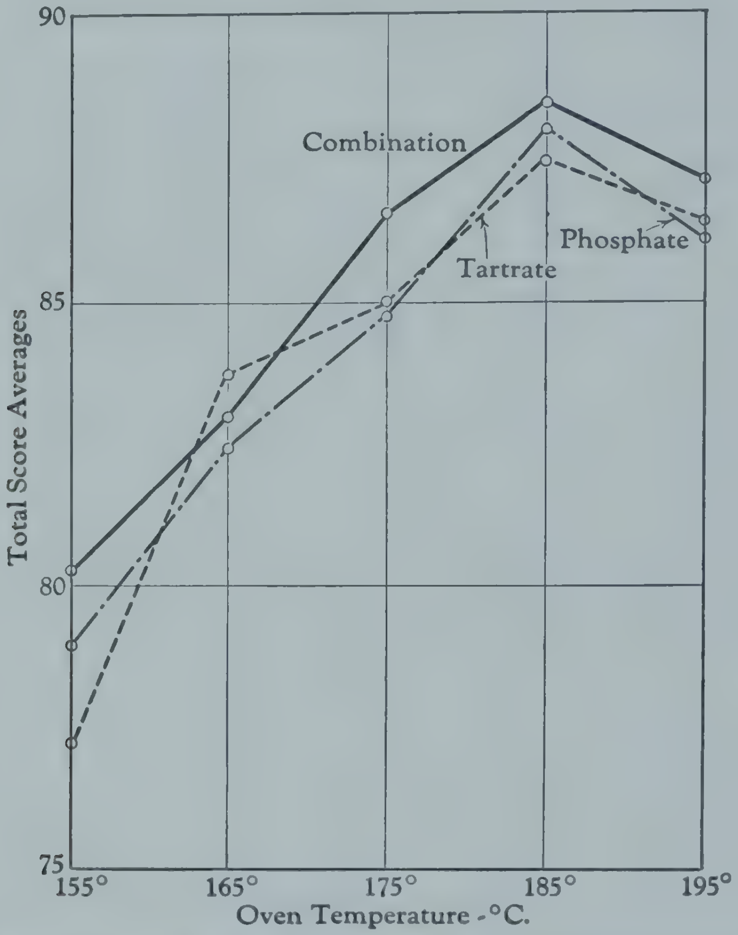


FIG. 63. The effect of baking temperature on the average cake scores for plain cake when three types of baking powder were used (*Stone*).

Sugar content and baking temperature. As sugar delays coagulation of egg proteins, the larger the amount of sugar, the greater is the effect. Sugar is said (39) to disperse flour proteins. Woodruff and Webber (77) have shown that better-formed starch gels result from rapid than from slow heating. Increase in sugar also increases the tenderness of starch gels (76). The effect of sugar on starch and proteins and the rate of heating on starch gels give at least a partial explanation for the improved texture of cakes that contain a high sugar ratio, when baked at higher temperatures.

The effect of a high sugar ratio upon volume and palatability (21, 66) when the batter is baked at temperatures of 175° to 225°C is illustrated in Figs. 64 and 65. Note also that, when the sugar is increased still further (*C* in Fig. 64), the volume is smaller. A cake with a high proportion of sugar needs a higher baking temperature than one with a small proportion.

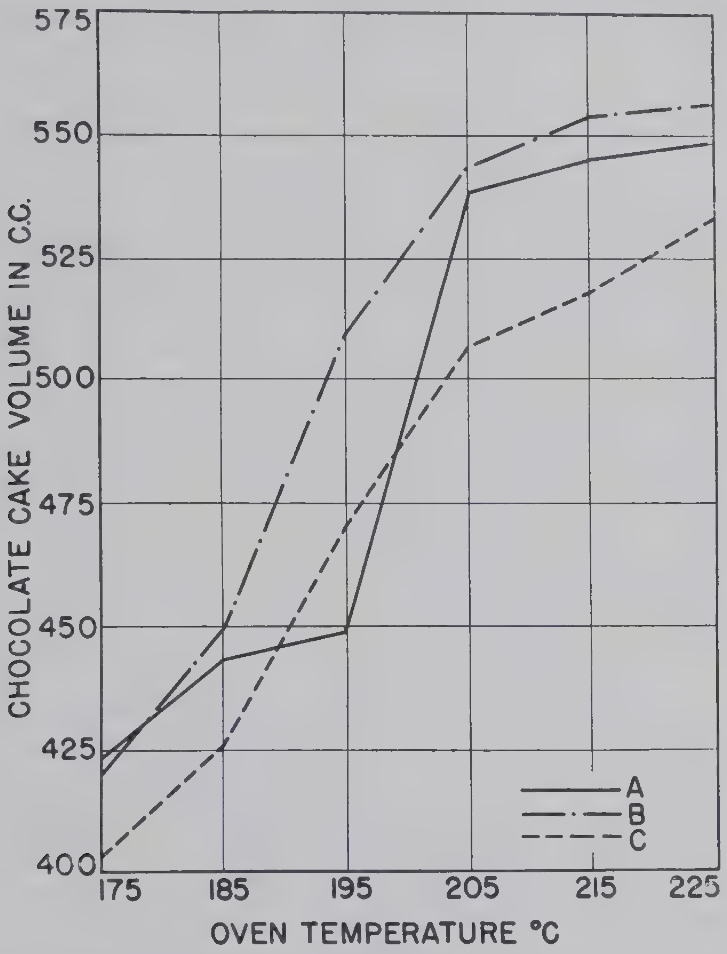


FIG. 64. The effect of baking temperature upon the volume of chocolate cake. The basic recipe used follows: Butter 224, sugar 400, egg 192, chocolate (4 squares) 113, cake flour 300, milk 244, baking powder 17.5, vanilla 5, and salt 2 grams. *A*, temperature of chocolate when combined with the creamed mixture, 40°C. *B*, temperature of chocolate 60°; and *C*, sugar increased to 450 grams, temperature of chocolate 40°C. The baking time at 175°C for a loaf cake containing 240 grams of batter was 39 minutes. The baking time was shortened 3 minutes for each 10°C increment of temperature (*Cook*).

The shape of the top and the way the cake shrinks from the sides of the pan are characteristic for each temperature. During the last of the baking period and cooling, the cake baked at the lowest temperature shrinks the most, both in height and from the sides of the pan. As the oven temperature is elevated, the shrinking progressively decreases, until none occurs in cakes baked at 195°C.

At the lowest temperature the top of the cake was level or had a slight depression in the center. As the baking temperature increased the top became rounded until at the highest temperature the top punched up in the middle entirely too much for a good appearance. There was a tendency for the cakes baked at 205° and particularly at 215° to become too brown on the edges. If these factors as well as eating quality are taken into consideration, the preferable baking temperature for these formulas appears to be 195–205°C (approximately 385–400°F).

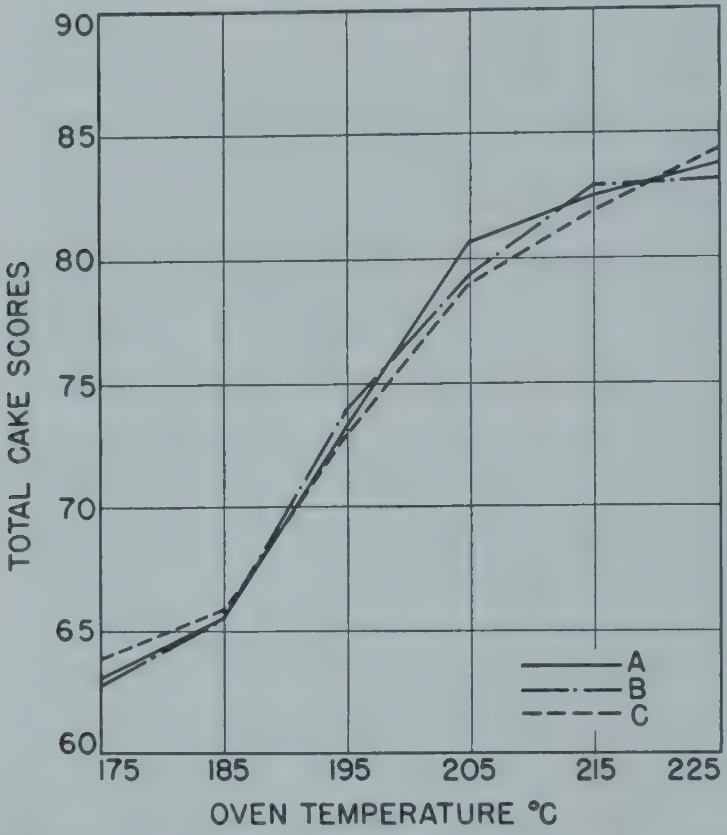


Fig. 65. The effect of oven temperature upon total scores of chocolate cake. The volume of the cakes is shown in Fig. 64 (*Cook*).

Schaal (60) suggests that for bakers' chocolate cakes about 195°C (380°F) is a good baking temperature. He says, "Bake the goods until they are just barely done. It is a mistake to overbake, since overbaking impairs the flavor just as much as a flashy oven, or an oven at too high a temperature."

Temperature for removing cake from the pan. Glabau (28) has reported that cake should not be removed from the pan or handled until its interior temperature has reached 60°C (140°F). The time for this varies somewhat with the thickness of the cake and the room temperature but is about 15 minutes or longer. When the cakes are first removed from the oven the structure is fragile. With cooling, the critical time for handling passes and the cake becomes sufficiently rigid to withstand the shock of handling.

Cakes, Methods of Combining Ingredients

The possible methods of combining are many. With the five ordinary ingredients for cake (shortening, sugar, egg, milk, and flour), depending on the order of adding ingredients 120 routines of combining are possible. If to these ingredients baking powder is added the possible routines immediately increase to 720. If flour, milk, and other ingredients are added alternately, the intricacies of mixing increase. However, it has been found that certain procedures of mixing have produced good cake, so that the usual methods of combining are not so numerous as might be expected.

For other discussions on methods of combining ingredients, see an article by Tinklin and Vail (69) and the bulletin by Hunter et al. (38).

The creamed mixture. A photomicrograph of creamed sugar and butter is shown in Fig. 66. The irregular white spheres and the two large squares are sugar crystals. The colored fat is adsorbed on the sugar. Butter contains moisture and partially dissolves the sugar. The rounding of the sugar crystals does not occur in a fat containing no moisture. If such a slide as that shown in Fig. 66 is used on a microprojector without a heat filter, the breaking air bubbles can be seen on the screen as the fat melts. The sugar crystals with adsorbed fat remain.

When egg is beaten into the creamed fat and sugar, Grewe (29) emphasizes that the egg-in-fat or water-in-fat emulsion obtained in this way is more stable if the egg is added slowly. When the fat was conditioned, *i.e.,* stored at temperatures of 19–25°C, more air was incorporated as the temperature was elevated. The amount of air enclosed in creaming increased for the three fats in the order named: butter, butter oil, and hydrogenated fat. Best results were obtained with 2 days' conditioning.

A partially creamed mixture of fat, sugar, and egg is shown in Fig. 67; a well-creamed one, in Fig. 69. Some of the air bubbles have fat around them; some are small white spheres. Probably both the amount of fat and its temperature (softness) influence the proportion of fat found around the air bubbles.

The irregular size and spacing of air bubbles in Fig. 68 is typical of a batter which produces a cake lacking in velvetiness. Such a distribution of the air bubbles is an indication of insufficient mixing, either of the creamed mixture or after adding the flour.

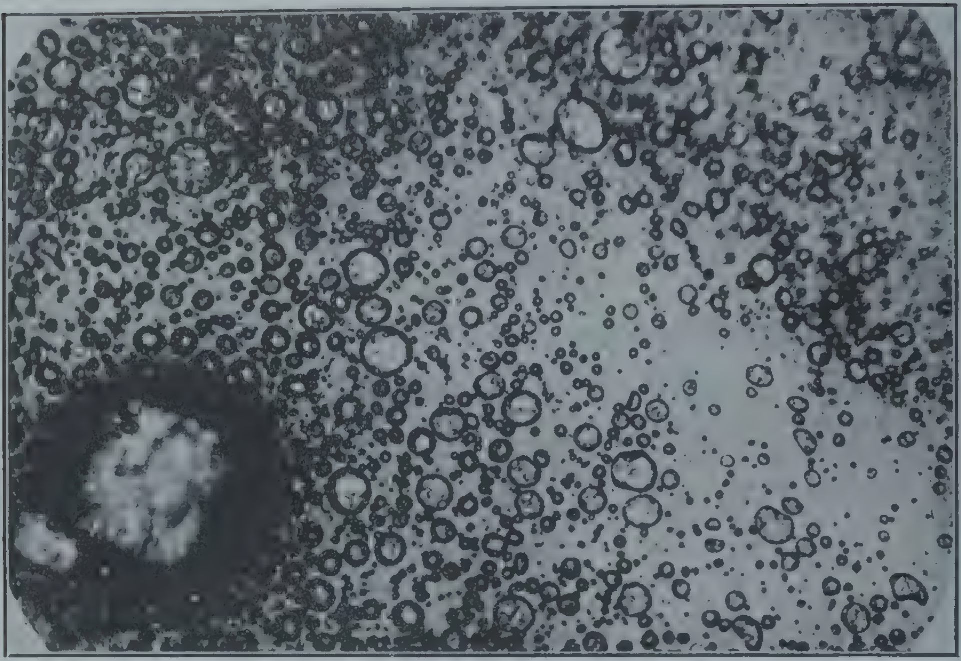


Fig. 66. Photomicrograph of thoroughly creamed butter and sugar. The butter, stained red, shows black in the picture. The small spheres with black outline and the tiny white spheres scarcely discernible in the picture are air bubbles. Magnification approximately x 100.

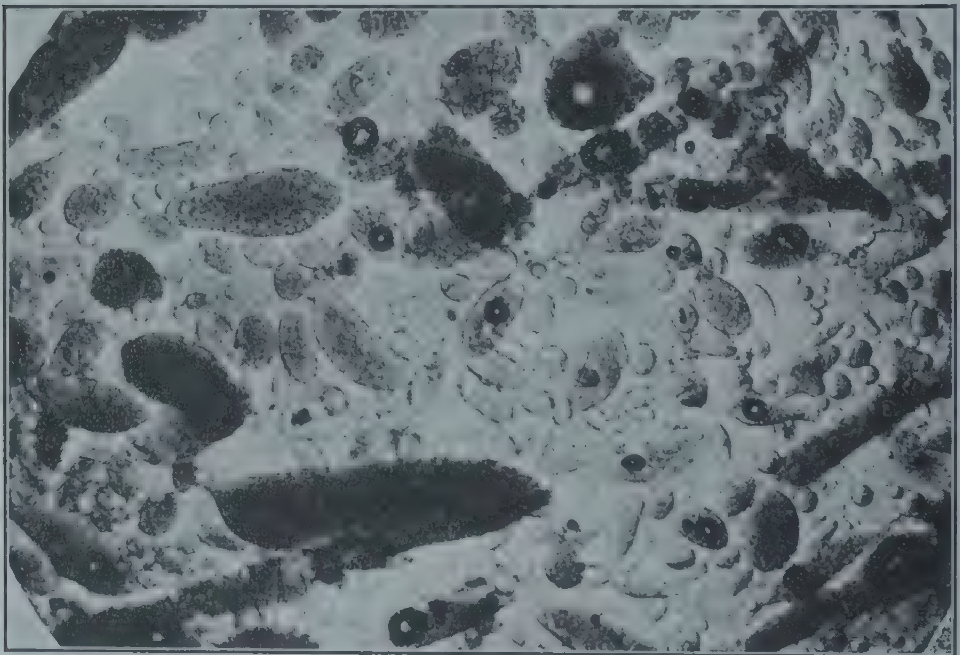


Fig. 67. Photomicrograph of partially mixed butter, sugar, and egg. That an emulsion has started is indicated by the spheres. Magnification approximately x 100.

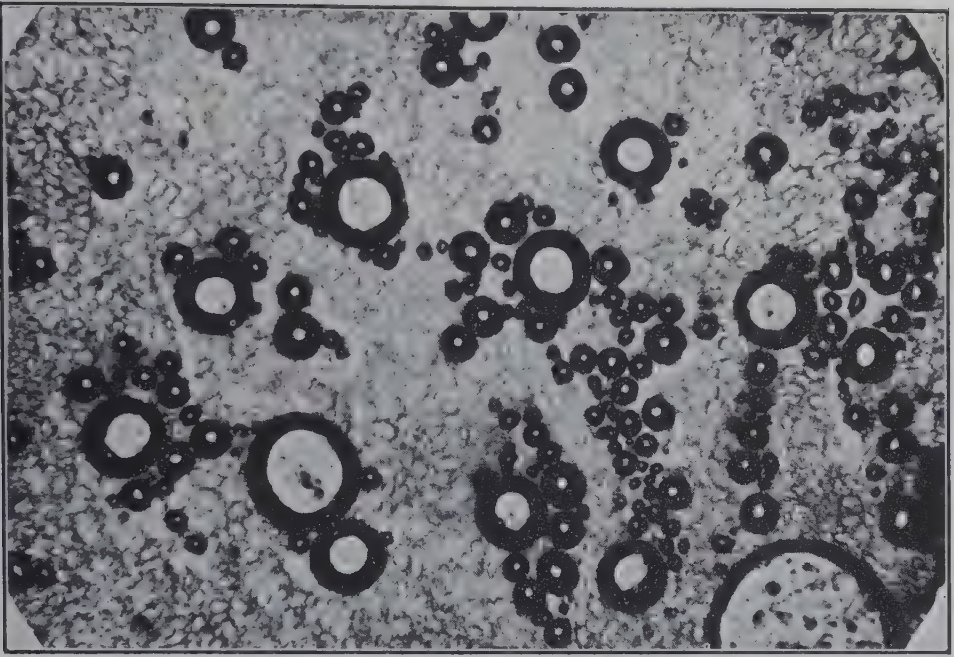


FIG. 68. Same as Fig. 67 after the addition of the flour and milk. The spheres with the heavy dark lines around them are gas bubbles. The irregular grouping of the gas bubbles and the difference in size are characteristic of the coarser texture obtained in the cake shown in Fig. 71. Magnification approximately x 100.

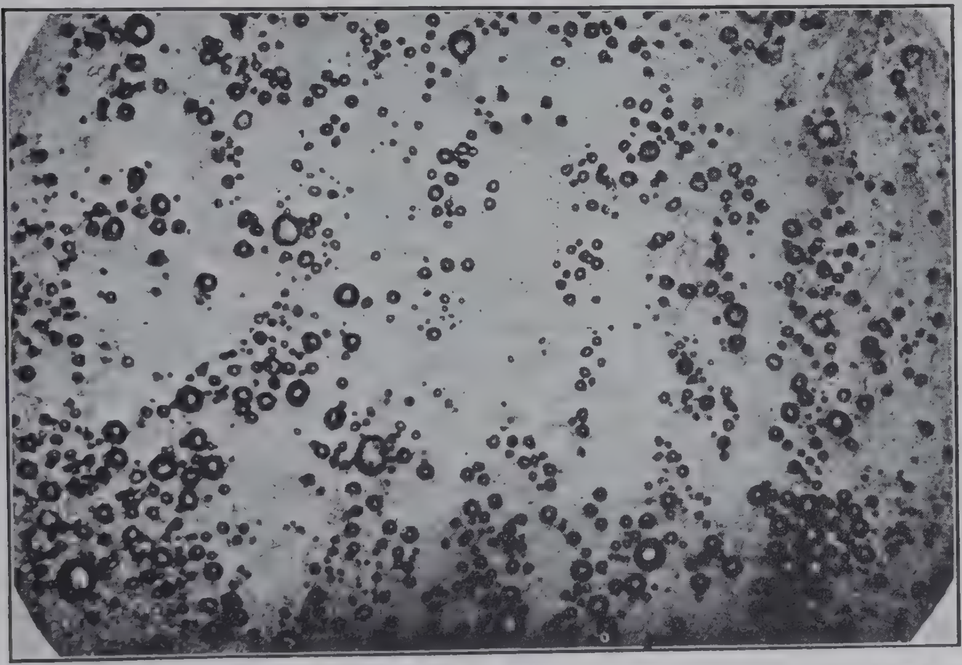


FIG. 69. The butter, sugar, and beaten eggs were put in the mixing bowl and creamed together until the mass was light and fluffy. Large sugar crystals were removed when the slide was made; others have dissolved. The small air bubbles, with dark line around them and as tiny white dots, are typical of a well-creamed mixture. Temperature of ingredients 22°C. Magnification approximately x 100.

The fat. Little air can be incorporated into oils or melted fats so that only the plastic fats can be creamed. Butter is preferred for its flavor. It performs better than lard, but not as well as some treated shortenings unless monoglycerides are added. Each fat has a temperature at which it creams best. This temperature is lower for the softer fats containing more unsaturated fatty acids, higher for the firmer ones. Farnham (25) used two family-sized electrically operated food mixers to cream two fats with sugar. The volume of the creamed mixes varied with the mixer used, its speed, and the temperature of the ingredients. The maximum volume was less at low than at medium speed. The time to reach maximum volume for both mixers was 27 minutes on low, 24 minutes on medium speed. The volume of the creamed mixture increased with elevation of the temperature to 25°C for butter, and 26.7°C for the hydrogenated fat.

Dunn and White (23) emphasize conditioning (holding at room or creaming temperature) of the shortening before creaming. The creamed volume and cake volume were greatest for the three fats used after conditioning for 200 hours at 21.1°C.

Creamed volume and cake volume. Studies in the author's laboratory indicate that for some fats there is not always a linear correlation between the creamed mix volume and the cake volume. However, what Martin (43) calls creaming quality is important and correlated to velvety texture and high-scoring cakes. By a good creaming quality is meant that a soft, spongy, light, not too frothy, curdled, runny, or pasty texture is obtained.

Conventional. In the commonly used household method for combining cake ingredients, the fat and sugar are creamed. Whole egg magma is usually added gradually to the creamed fat and sugar. For a white cake the beaten egg whites are usually folded into the batter last. For both white and yellow cakes, the flour (containing the baking powder) and the liquid may be added to the creamed mixture as follows: (*a*) all at once, (*b*) flour first and last, (*c*) portions of the flour and milk at the same time, and (*d*) milk first and last. See Experiment 57D. In general, the last three methods produce better-textured cakes than adding all the flour and milk at once. Methods *b* and *c* are probably used most frequently. Other variations of adding the egg white may be (*a*) creaming the egg white into the fat-sugar foam and (*b*) adding part of the egg white foam as the flour and liquid are added. See Experiment 60,4. The egg white foam is more stable if some of the sugar for the cake formula is whipped into the egg white.

The conventional method or some modification of it is good for making cakes at home, particularly if the fat has not been conditioned and all other ingredients brought to temperatures of 22–27°C (70–80°F) before mixing is started. If the fat is cold, it can be warmed by creaming, although more time is required to cream the fat and sugar under these conditions and a less desirable creamed mixture is obtained.

As emphasized under "The Structure of Batters and Doughs," p. 446, and as will be emphasized again, the ingredients, their temperature, concentration, and treatment, all have a decided effect upon the finished product. Figure 68 is a photomicrograph of a cake batter. In the batter a major portion of the fat encloses the air bubbles. This unequal distribution of the fat and the air bubbles is typical of a batter which produces a cake which lacks velvetiness of crumb and is coarser in texture as shown in Fig. 71. The more even distribution of the air and fat, shown in Fig. 70, produces a cake of better texture, Fig. 72. The distribution of fat can be made more uniform, the air bubbles smaller and more numerous by using a fat that contains monoglycerides. This will be discussed later.

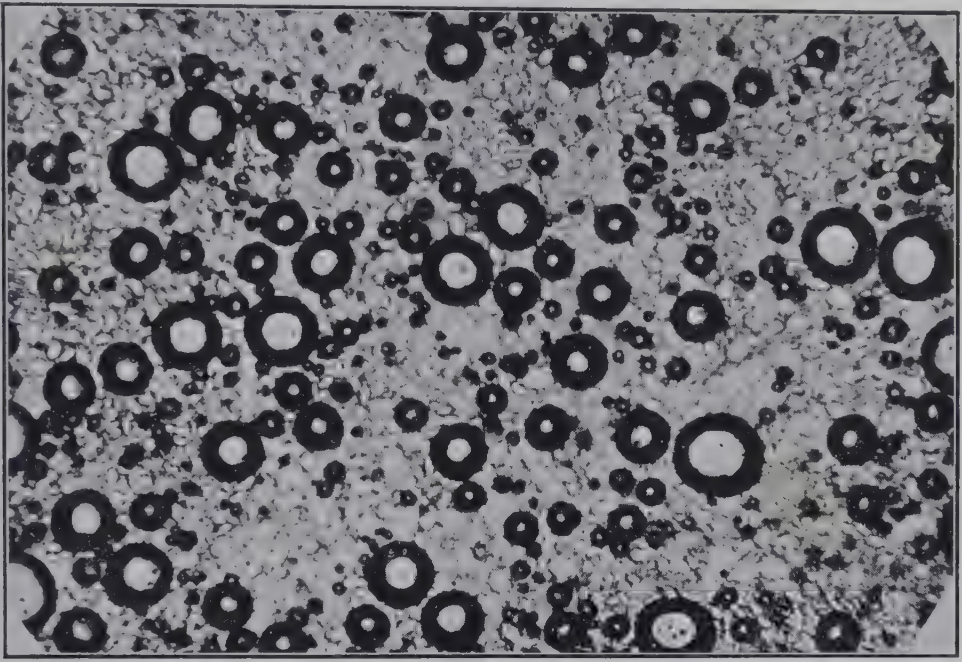


FIG. 70. Photomicrograph of cake batter. Same as Fig. 69 after adding the flour and milk. Note the regular grouping of the air bubbles in contrast to those in Fig. 68. All batters observed microscopically that have had small gas bubbles with even distribution have resulted in cakes of excellent texture. See Fig. 72. Magnification approximately x 100.

Modified conventional. This method varies from the conventional one in the creaming process. The fat, softened to 22–28°C, the egg, and the sugar are all placed in the bowl at the same time and creamed with an electric mixer, an egg beater, or a spoon. The egg beater can be used until the mass becomes too stiff. The creamed mass is more likely to separate into fine curds than when the egg is added slowly as in the conventional method. Yet if the curds remain fine, cakes of excellent texture can be obtained.

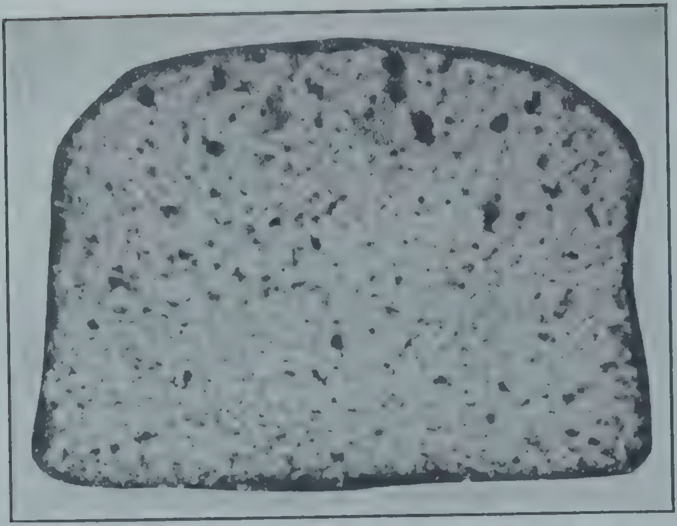


FIG. 71. The plain cake formula I, Table 36, was used for the cakes shown in Figs. 66–71. The above cake is made from partially creamed sugar, butter, and egg as shown in Figs. 67 and 68.

Single stage. This is the method that has been used as the official A.A.C.C. cake test (2). All the ingredients are preconditioned to obtain a batter temperature of 25°C. The shortening, emulsifier, and liquid are placed in the bowl. The dry ingredients are blended, added to the above, mixed 0.5 minute at low speed, 1.5 minutes at high, and 0.5 minute at low speed.

However, Sundberg et al. (67) state that a two-stage method is much more sensitive than the single-stage in showing differences between flours. In their two-stage method the sugar, shortening, and emulsifier were creamed before the dry ingredients and liquid were added.

Muffin. This is a household method, similar to the A.A.C.C. single-stage procedure, except that the baking powder is added with the other ingredients and the fat is melted. All the dry ingredients are combined and added to the liquid ones. The advantage of this method is that the batter can be mixed in a short time. If the fat remains melted, an oil-in-water emulsion is formed of part or all of the fat. The batter is thinner and more runny than when the same ingredients are mixed by the conventional or single-stage methods. The resulting cake is rather tough and rubbery in texture. It is not velvety. The cells are rather large, and the crumb is coarse in texture. The top of the cake peaks more in baking than if made by the conventional method and has a shinier appearance. It is a rather poor method for mixing cake ingredients.

Emulsion. If an oil-in-water emulsion is desired in a cake batter, why not mix the batter by a method that will give the most stable oil-in-water emulsion? The oil or melted fat is added gradually to the beaten egg as in making mayonnaise. The sugar is added to the emulsion, then the flour

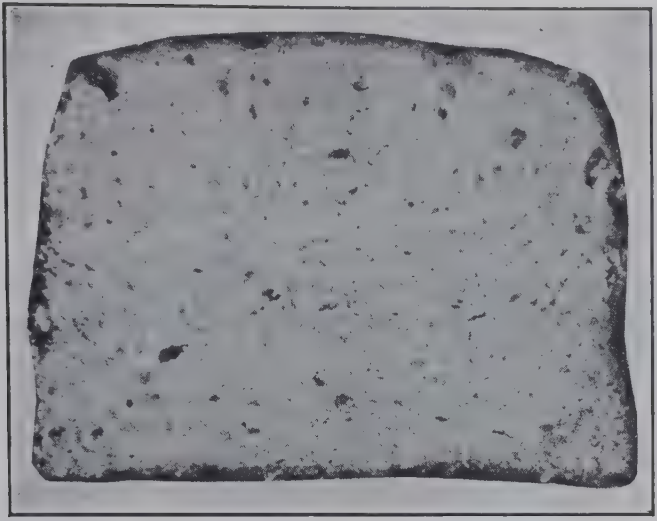


FIG. 72. The above cake is from the creamed mixture and batter shown in Figs. 69 and 70. The flour and milk were added alternately in thirds, for cakes Figs. 71 and 72, with a total of 225 strokes.

and liquid. This method proved to be a poor one for mixing cake. The results are similar to those by the muffin method.

Conventional sponge. To date, the conventional sponge method used in our laboratory produces a good cake from melted fat or an oil. It also is the best method to use with the semiplastic, soft lards. This has been confirmed by Ohlrogge and Sunderlin (51). The batter is mixed in the same way as for the conventional method, except that half of the sugar and the whole egg are added last. A small amount of flour is folded into the creamed mixture. Then the rest of the flour and the liquid are added. The second half of the sugar is beaten with the whole egg with an electric mixer until the whole mass is light and fluffy and looks like sponge cake batter. This is added to the cake batter. This sponge supplies the many air bubbles which are needed for good cake texture and which cannot be incorporated into a melted fat or an oil. The method was developed from observing that a spice cake made from soft, grainy lard, but with no egg, had excellent, very velvety texture. This suggested adding the egg late in the mixing process. Martin (43) developed several methods of combining lard in cake. When the egg was thoroughly mixed with the milk and the milk added as usual the texture of very soft lard cake was improved. The conventional sponge method gave still better results.

Flour-batter. In this method the fat is mixed with the flour in the same manner as for pastry. The baking powder was sifted with the flour before mixing with the fat. Next the sugar is whipped into the egg by an electric mixer or egg beater. The whole-egg meringue and the milk are added to the fat-flour mixture. Martin (43) found that this method produced cake of excellent texture and volume.

Sugar-water. This method is reported by Stateler (64) from the American Institute of Baking. Part of the liquid and sugar are mixed until the sugar is dissolved. Then the shortening, flour, baking powder, and salt are added and mixed until the batter is well aerated. The whole eggs, the flavoring, and the other portion of the liquid are added last. The method is said to require less baking powder, gives a finer grain, and a cake of better volume than the old method.

Factors Affecting the Distribution of Fat in the Creamed Mixture, the Batter, and the Cake

The distribution of fat in the creamed mixture, the batter, and the cake may be affected by several factors under the same or different mixing conditions. Among these are the temperature of the ingredients and room, the *p*H, the kind of fat, the other ingredients and their proportions, the method of combining these ingredients, and the baking temperature. As the temperature is raised a plastic shortening becomes softer, more mobile, until it is melted. As these steps occur the fat becomes easier to emulsify as an oil-in-water emulsion.

The kind of fat. The possible fats for cakes are the oils, lard, butter, and the hydrogenated shortenings. Oils and soft lards have shortcomings unless combined in special ways. Butter is expensive. The hydrogenated shortenings (the source may be lard or oils of soybean, cottonseed, or peanut) are most frequently used. At the present time most of these retail hydrogenated shortenings contain antioxidants and commercial monoglycerides. The commercial monoglycerides are a mixture that contains about 40% mono-, 55% di-, and 5% triglycerides. The monoglyceride mixture is a surface-active agent and increases the dispersion of fat and water. This allows more water and sugar to be used in the formula. The mono- are more powerful surface-active agents than the diglycerides (41).

The creamed mixture. Grewe (29) has shown that when the egg is added slowly to a fat-sugar foam at 22.5°C the resulting egg-in-oil emulsion is most stable for the three fats used at *p*H 4.8.

The batter. Carlin (15) states that Grewe was correct in the type of emulsion reported when egg is added slowly to the fat-sugar foam. He comments that it is difficult to attach much significance to the state of the emulsion at this stage of the procedure. He found that the major portion of the liquid (egg) was released from its emulsified state by the addition of flour. He adds that it was evident that a continuous water-in-fat emulsion did not exist in the batters that he studied (poundcake and white layer cake).

All the studies on fat distribution in cake batter and cake in the author's laboratory reported in the previous edition were for fats containing no glycerides. Jooste and Mackey (40) and Carlin (15) show photomicrographs of the distribution of fat containing emulsifiers in cake batters.

With butter and with hydrogenated shortening the fat was distributed in clumps, somewhat as shown in Fig. 68. The air was occluded or suspended in these clumps or lakes of fat. More air bubbles were dispersed in the hydrogenated shortening than in butter (40). Carlin varied the amount of emulsifier added from 0 to 9% (fat basis). With each added increment of emulsifier the fat and occluded air bubbles became more finely dispersed. The microscopic appearance of the batters was different with the monoglycerides. The cake batters (40) made with butter and a hydrogenated vegetable shortening without the monoglycerides were aerated, light and thick, resembling whipped cream. The batter showed a tendency to break or curdle. With 6% (fat basis) of the emulsifier the batters were smooth, glossy, and relatively thick. They showed a slight tendency to flow but no separation or curdling occurred. With 3% monoglycerides the batters were intermediate between those with 0 and 6%.

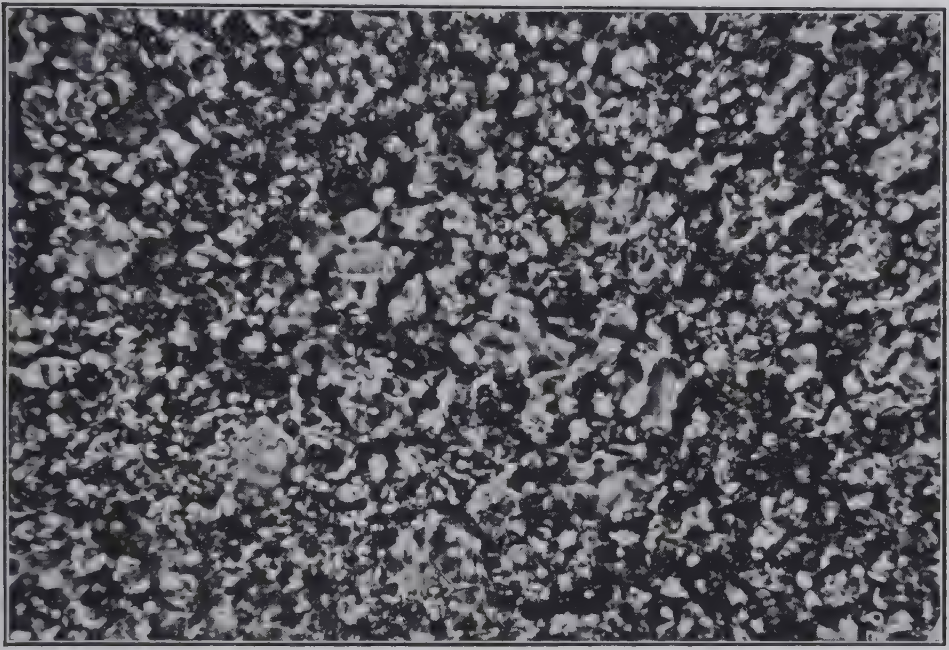


FIG. 73. Cake batter. The temperature of all the ingredients was 40°C when combined. At this temperature the butter was melted. The small spheres are numerous and appear to be completely distributed as an oil-in-water emulsion. The butter was dyed dark red with scarlet R so that the fat appears black in the photomicrograph. The material on the slide was too thick for the magnification necessary to show the fat distribution. At magnification of 100 the whole batter appeared pink and the spheres were not noticeable. Magnification approximately x 400.

When the temperature of the cake batter is high, so that the fat is melted, the fat is dispersed as a fine oil-in-water emulsion in the batter. See Fig. 73. The muffin and emulsion methods of mixing, unless the temperature is very low, give oil-in-water emulsions of the major portion of the fat. Although no studies of creaming egg yolk instead of egg magma with fat have been reported, it is possible that egg yolk may tend to give an oil-in-water emulsion. Egg yolk (see the chapter on Emulsions) tends to emulsify oil as oil-in-water emulsion. Egg white has this tendency to a far less degree.

Viscosity of the cake batter. It has been observed in the author's laboratory in the studies on cakes that a relationship exists between the batter and the cake, thin runny batters producing inferior cakes, whereas viscous ones produce more desirable cakes. These comments refer to batters in which the proportion of ingredients is balanced, for an unbalanced formula, such as one with too much flour, may give a very stiff batter. Between these two extremes, which can be produced from the same proportions of the same ingredients, are batters of varying degrees of viscosity. Sunderlin and Collins (68) have observed similar relationships. This observation that more viscous batters produce better cake needs to be revised for fats with which monoglycerides are used. Carlin (15) observed that batter from fat plus monoglyceride was less viscous than batter from the same fat without the monoglyceride, yet the fat with the emulsifier produced the better cake.

The cake. Carlin's (15) description of baking batter is given under what happens during baking, p. 460. The melted fat freed of its air bubbles collects in small lakes throughout the baking batter. These fat lakes are smaller when an emulsifier is used. There is little coalescing between separate fat areas, but much coalescing of gas bubbles.

Morr (49) used six fats, combining them by two methods, to study the relation of kind of fat and method of mixing to fat distribution, cake volume, palatability scores, and objective tests. Some of the data are given in Table 35.

TABLE 35

AVERAGE VOLUME AND TOTAL CAKE SCORES FOR SIX FATS AND OIL COMBINED BY TWO METHODS (each figure the average of 15 tests) (*Morr*)

Fat	Volume, cc Conv.	Volume, cc Conv.-S.	Total cake scores Conv.	Total cake scores Conv.-S.
Butter	481	481	80.2	83.0
Hydrogenated lard	474	461	79.7	82.9
Open-kettle rendered lard	476	471	76.5	80.3
Hydrogenated vegetable oil 1	489	444	79.5	80.3
Hydrogenated vegetable oil 2	489	443	79.3	81.0
Cottonseed oil	401	479	41.7	50.9
Method means for all fats	468	463	72.9	77.9

Morr (49) stained the fat in the cake with osmic acid fumes. The starch distribution was noted by staining sections of the cake on slides in iodine solution. The parts staining blue were elongated and somewhat bean-like in shape. These blue-staining portions were often distributed in the marginal layer of the fat at the cake/air interface, this distribution occurring more frequently with the conventional sponge than in the conventional method. When the portions staining blue were within the interior of the crumb they often had a layer of fat partly or completely around the stained area. Aqueous eosin was used to determine the protein distribution. The parts staining blue with iodine did not stain with eosin. Eosin stained the proteins of flour, egg, and milk. The starch and fat were embedded in or at the surface of the protein matrix.

The distribution of butter in the cake crumb is shown in Fig. 74. The distribution of the fat in the cake crumb was affected by the method and temperature of combining ingredients. The kind of fat also brought about characteristic differences in the cake structure. At 25°C the fat in the cake crumb, depending somewhat on the method and the fat used, is more or less evenly distributed within the crumb and at the air/crumb interface. The fat appeared to be more evenly distributed within the crumb in the conventional sponge than in the conventional method. When the ingredients were combined at 30°C the fat is within the cake crumb, with none or very little in a layer at the air/crumb interface. In general, the fat particles are smaller and more uniformly dispersed than at 25°C. The cakes mixed at the lower temperature were considered superior to those mixed at the higher temperature. The butter appeared to be most finely divided throughout the crumb of the cake. The hydrogenated fats were in clusters, mostly at the cake/air interface, with some fat distributed through the crumb. The oil cakes had the coarsest, thickest, most compact cell walls. They had heavy coatings of oil at the air/crumb interface.

Effect of emulsifier. The addition of an emulsifier affects the structure of the batter and also that of the cakes obtained from these batters. Jooste and Mackey (40) added glyceryl monostearate dispersed in fat and in water solution to butter and hydrogenated vegetable-oil cakes. Schoenleber (66) used commercial monoglycerides dispersed in butter in cake. Favor et al. (26) were interested in the effect of emulsifiers on the volume of prepared cake mixes. They used monoglyceride and polyoxyethylene-type emulsifiers. Carlin (15) used mono- and diglycerides in both poundcake and white layer cake.

Addition of the emulsifier increased the dispersion of the fat in the batter (15, 26, 40) and gave a smoother, less viscous batter than when no emulsifier was used (15, 40, 66). Jooste and Mackey report a better dispersion of the fat in the batter when the emulsifier was added in the fat than when added in a water dispersion. They also found that more gas bubbles were dispersed in the hydrogenated vegetable shortening than in the butter cake batters.

Addition of the emulsifier had the following effect upon the cakes as compared with cakes made without emulsifier: better volume and better texture, the cell walls being thinner and the cells smaller (15, 26, 40, 66),

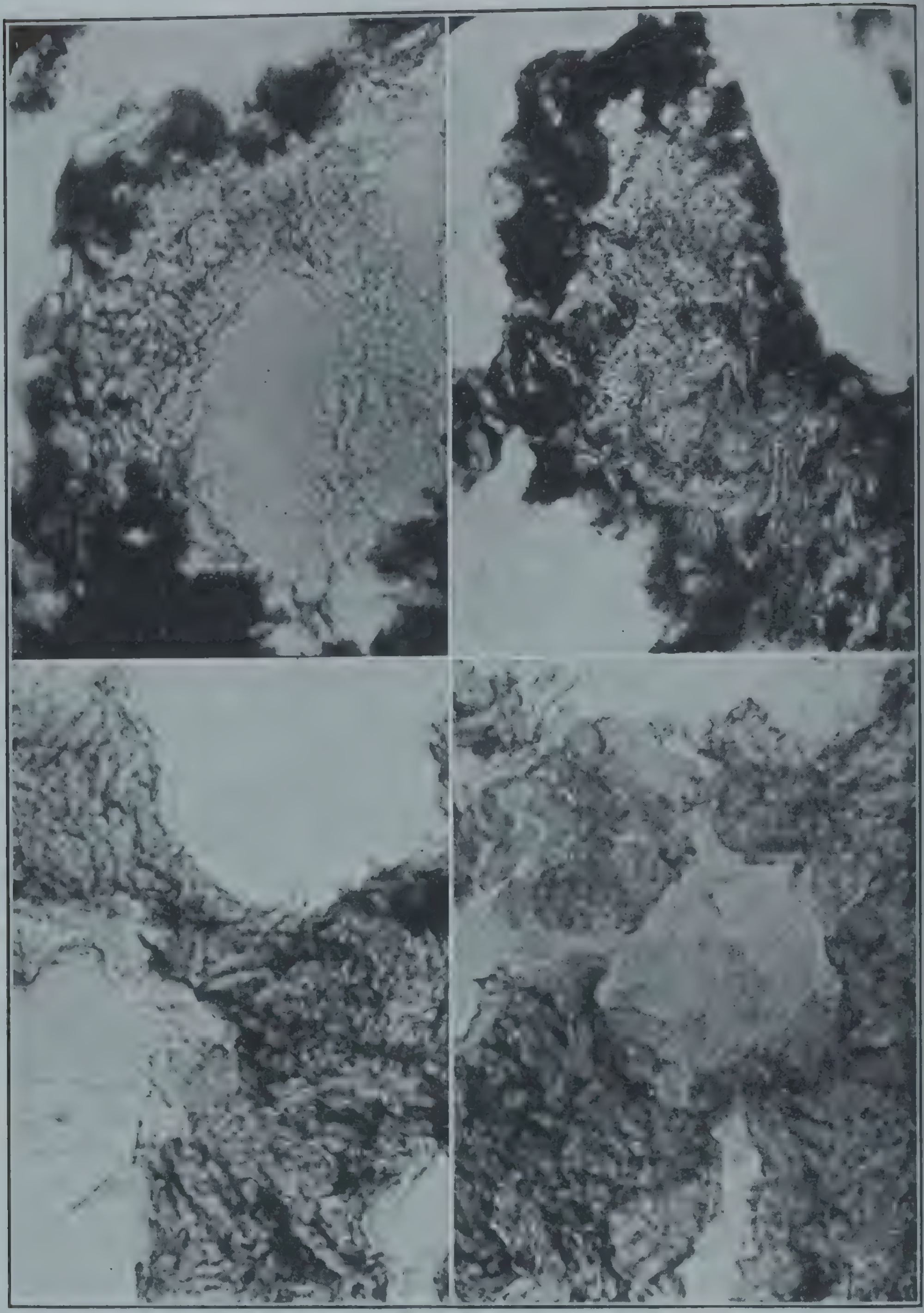


FIG. 74. The distribution of fat (butter) in cake crumb as influenced by method of mixing and temperature of ingredients when combined. At the lower temperature more of the fat (black in the photomicrographs) is at the surface of the cake crumb, but the layer is more uneven in the conventional than for the conventional sponge method. At the higher temperature the fat is softer and is distributed within the cake crumb, resulting in a cake of poorer texture. Magnification approximately x 350.

Upper left: Conventional method, ingredients mixed at 25°C.
Upper right: Conventional sponge at 25°C.
Lower left: Conventional at 30°C.
Lower right: Conventional sponge at 30°C (*Myers*).

and smoother, less blistery crusts. In addition Jooste and Mackey report that the effect on volume varied with the fat used. They obtained larger volume with butter than with the hydrogenated vegetable-oil cakes, although the latter had more air dispersed in the batter.

Favor et al. (26) found that emulsifiers not only increased the volume of white cake mixes but a still larger volume was obtained if the shortening was also increased to a maximum amount.

Amount of emulsifier. The addition of 3% emulsifier (on the basis of weight of fat used) produced as large a volume as 6% (40, 66). On the other hand, Carlin found the volume of the cake to increase with added increments of emulsifier up to 5–6%.

Baking. Jooste and Mackey used the following oven temperatures: 149°, 163°, 191°, and 218°C (300°, 325°, 375°, and 425°F). They found that cakes with emulsifiers increased in volume as the oven temperature was raised and also received higher palatability scores.

Extent of Mixing and Its Effect on Cake

For the illustrations that accompany this part of the discussion of cakes, 150 grams of batter were always used and the cakes were baked in small, straight-side pans of the same size. The illustrations for Fig. 78, as well as Figs. 52 and 53 for the angel cakes, were obtained by the method of Cathcart (16), *i.e.,* by printing with light through the cake slice. The small amount of batter used was chosen so that the grain, holes, and imperfections of texture and the volume are shown nearly actual size. The very plain cake recipe (see Experiment 57) is used in the experimental outline because variations in extent of mixing and the proportion of ingredients show very distinctly. For a plain cake recipe for home use, most people will prefer the sugar increased to 1.5 cups.

Effect upon crust and shape of cake. With very little mixing, so that the ingredients are just combined but not blended until the batter is smooth (cake 1, Fig. 75) the top of the cake is nearly level or slightly rounded. It browns well and is rough. The crust has considerable glaze. As the amount of mixing is increased the crust is less rough, has less glaze, does not brown so well, and is more rounded across the top, until with more than an optimum amount of beating, 300 to 400 strokes in this cake, the crust becomes dull in appearance and quite smooth. There is a tendency for the top to come to a peak instead of being rounded. Small holes may be noticeable. Over these holes there is often a very thin layer of crust that covers the end of a long tunnel that extends up through the cake. With decided excess of mixing, 1000 strokes, the top may be level or only slightly rounded and is very dull and smooth in appearance and nearly white in color. The appearance of the crust of cake made with sulfate-phosphate baking powder changes with increased mixing but not so rapidly as that of the cakes made with the phosphate or tartrate baking powder.

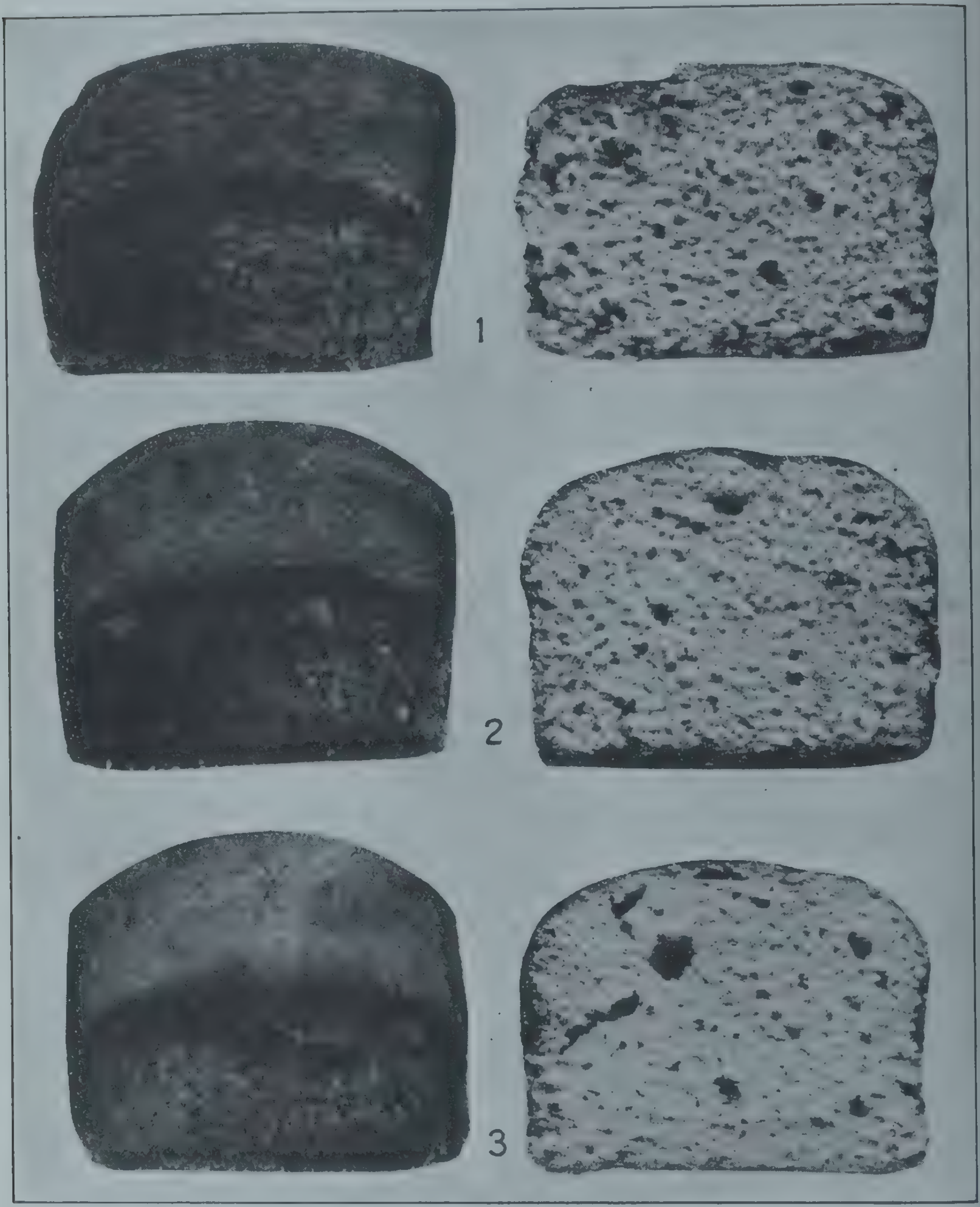


FIG. 75. Cake. Showing effect of extent of mixing on volume and texture when a tartrate baking powder is used. Experiment 57A. As shown in illustration the cakes are about seven-ninths actual size.

One hundred and fifty grams of the batter removed and baked after mixing.

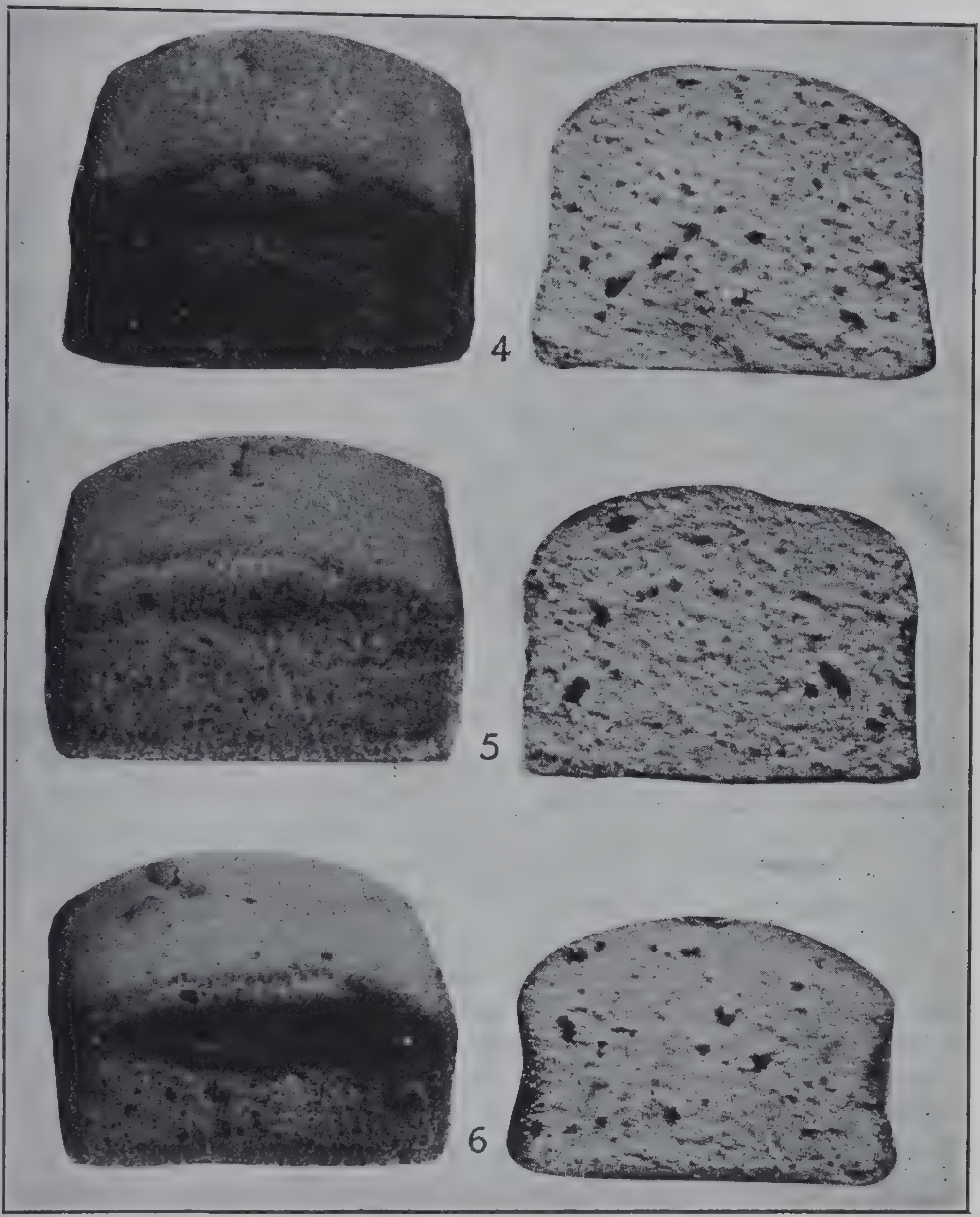


FIG. 75.
1. 50 strokes.
2. 100 strokes.
3. 150 strokes.
4. 300 strokes.
5. 400 strokes.
6. 1000 strokes.

Effect upon volume. When the cake is just mixed so that no dry ingredients show, the volume of the cake may be less than when the batter is stirred a little longer, or it may be larger. With more mixing, 100 to 150 strokes, the volume may or may not increase. Continued beating after an amount sufficient to give the maximum volume decreases the volume in proportion to the degree of overmixing. With more than an optimum amount of mixing the volumes of cakes containing a phosphate or a tartrate baking powder decrease more rapidly than those of the cakes made with sulfate-phosphate baking powder.

Effect upon texture. With a definite proportion of ingredients the texture of the crust and the volume vary with the extent of mixing. The cakes in which the ingredients are just mixed so as to show no dry flour do not have a desirable texture. See cake 1, Fig. 75. The ingredients of the cake are not well blended, and the crumb has a horny, flinty texture, which is sometimes called bready. The crumb is crumbly, not smooth and velvety on the palate. The cell walls are thick and the cells coarse and large. A cake made with this amount of mixing dries out and stales in a very much shorter time than portions of the same batter mixed for a longer time. With more mixing the grain of the cake is finer and the cell walls thinner. The crumb is smooth and velvety when tasted, and the ingredients are well blended. With a definite amount of mixing of the plain cake batter, 150 to 400 strokes, which varies somewhat with the kind of baking powder used, the maker's technic, and the temperature of the ingredients, tunnels begin to appear. More mixing than the optimum produces a finer grain, or smaller cells, until a stage is reached, 1000 strokes or more, at which the texture is very compact or even soggy and solid.

It has been shown that extended mixing of bread dough modifies the quality of the gluten, and its extensibility is decreased. It seems logical to expect this stage to develop in cakes as well as in bread, although on account of the different proportion of ingredients the amount of mixing to bring this about may vary from the amount required for bread. Several factors may aid in producing the small volume with 1000 strokes: the extent of mixing, its effect upon the gluten, the effect of the baking powder upon the gluten, and the loss of CO_2 formed from the baking powder.

Tunnels. Tunnels in cakes develop in the same way as in muffins.

Optimum amount of mixing for plain cake. In the plain cake the optimum amount of mixing varies with (*a*) the thoroughness of creaming, (*b*) the intensity of mixing, (*c*) the temperature of the ingredients, (*d*) the type of baking powder used, (*e*) the quantity of baking powder used, and (*f*) the point at which the baking powder is added. When the butter, sugar, and egg are thoroughly creamed, the optimum amount of mixing may extend over a wider range. Most of these factors have been considered. For the very plain cake recipe, when a phosphate or tartrate powder is used, about 150 to 200 strokes give the best texture, if the baking powder is added with the flour. A sulfate-phosphate powder requires about 250 to 300 strokes for the best texture. As the sugar in the recipe is increased to give a more desirable cake, the optimum amount of mixing is greater, but is more nearly the same for all the different types of baking powder.

For formula I, Table 36, with 1.5 cups of sugar, which is a more desirable plain cake than the formula given under Experiment 57, about 225 to 250 strokes, or sometimes more, are sufficient for mixing the flour and milk with the creamed mixture to produce a good texture.

Effect of mixing on staling. Olsen (52) used the compressibility apparatus designed by Platt (56) in trying to determine the effect of extent of mixing upon the staling of plain cake. It was found that cakes mixed for different lengths of time could not be compared with each other. Those mixed for a very short period had a loose, coarse, porous texture, which permitted greater penetration of the plunger into the crumb. The cakes mixed for a longer period were compact in texture and offered more resistance to penetration of the plunger. It was found that there was a tendency for the cakes creamed a short time to stale more rapidly than those creamed for a longer period. The rate of staling was greatest during the first 24 hours. It was less rapid from 24 to 48 hours and continued at a still slower rate from 48 to 96 hours. Formula I was used for tests.

Cake, the Ingredients and Their Proportion

Baking powder. Patterson (53) states that a very fine baking powder should be used, so that small bubbles are formed. With many large bubbles of gas formed at the same time, the cell walls may be subjected to too great a pressure and collapse, producing a fallen cake.

The proportions of baking powder. McLean (45) used varying amounts of three types of baking powder to determine the optimum quantity of each powder for plain cake (formula I, Table 36).

The effect on the cake volume of increasing the baking powder is shown in Fig. 76. The volume increases with increased quantity of powder until a point is reached at which the cake falls, the volume decreasing with still greater increments of baking powder. This decrease in volume occurs with a larger quantity than that shown in the graphs, about 20 grams for the combination or sulfate-phosphate and 24 for the tartrate and phosphate types.

From Fig. 77 a comparison may be made of the change in score caused by increasing the weight of a tartrate, phosphate, or a sulfate-phosphate (combination) powder in plain cake and again a comparison may be drawn between the scores for cakes made with an equal weight of the three different types of baking powder. McLean found that the palatability and desirability of the cakes, as shown by the scores, progressively increased with increased weight of the powders until the optimum quantity of baking powder is reached. With a further increase beyond the optimum amount the desirability of the cakes decreased. The decrease in desirability was most rapid with the powder giving the greatest volume, indicating that it is more detrimental to use too much of a sulfate-phosphate baking powder than of a tartrate or phosphate. For the formula, the method of mixing used, and for the brands of baking powder used in the investigations, the optimum quantity of each powder was as follows: sulfate-phosphate, 8–10 grams; tartrate, 10 grams; and phosphate, 12 grams.

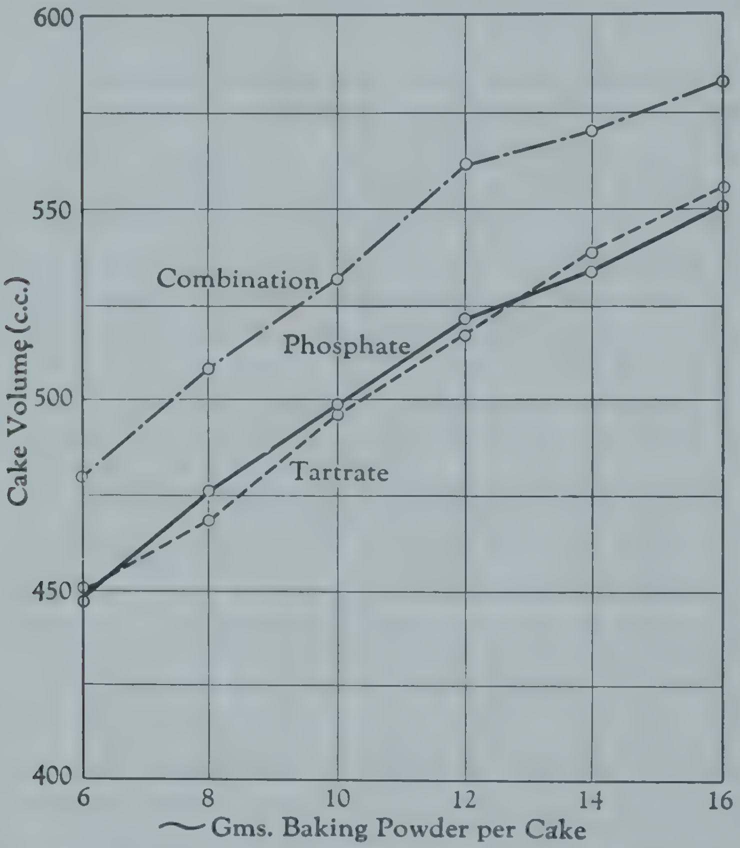


FIG. 76. The effect on volume of increasing the quantity of three types of baking powder in plain cake, sulfate-phosphate (combination), tartrate, and phosphate (*McLean*).

An increase in the quantity of a baking powder over and above the optimum amount causes an increasing tendency to produce a coarse, loose texture, crumbliness, a harsh crumb, a lack of velvetiness, and a possible off flavor. With enough baking powder to cause the cake to fall an increasingly gummy, sticky, chewy texture is obtained. Too little baking powder gives a cake that is too compact.

The measure of the optimum amount of each type of powder as determined by McLean is approximately 3 teaspoons, if the average weight of a teaspoon is taken as 3, 3.5, and 4 grams for the sulfate-phosphate, tartrate, and phosphate baking powders, respectively. Since 3 cups of flour were used in the recipe, this would indicate that it is possible to use 1 teaspoon

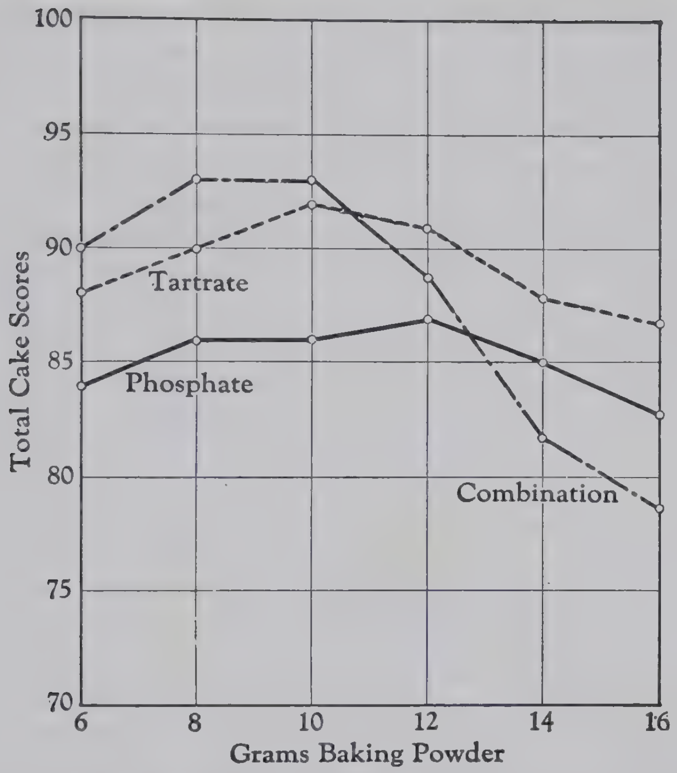


FIG. 77. The effect on total scores of increasing the quantity of three types of baking powder in plain cake. Each point on the graph is an average of scores for 14 cakes (*McLean*).

of baking powder per cup of flour for all three types of powders. Since a teaspoon of some brands does not weigh the same as the brands used by McLean, the measure for these brands would vary. Probably the chief reason for the variation in weight of different types and different brands of the same type is the fineness of subdivision or grinding of the ingredients.

The following weights for a teaspoon of baking powder have been suggested and used.

TYPE OF POWDER	*Halliday and Noble* GRAMS PER TEASPOON	*Woodruff* GRAMS PER TEASPOON
Phosphate	4.00	3.52
Tartrate	3.67	3.07
Sulfate-phosphate	3.70	2.85

The weights by Woodruff (75) were determined by finding the average weight of a cup of the powder and taking 1/48 of this for the weight of a teaspoon. From the above weights it can readily be calculated that 3 teaspoons of the sulfate-phosphate powder by the Halliday and Noble (33) scale are equal to about 4 teaspoons by the Woodruff scale. When measured by teaspoons rather than by cups the averages of Woodruff are low.

The weight of a teaspoon of baking powder can vary considerably even when a standard measuring spoon is used. For accurate experimental work the baking powder is weighed, but the housekeeper usually measures the ingredients for her cakes. Dipping the measuring spoon into the can and leveling off the surplus tends to loosen the powder. Thus the weight of the second or third teaspoon of powder will vary, depending on whether it is secured from the loosened or the more compact portions in the can. As the powder stands in the can it tends to become more compact. The averages for about 400 teaspoons of each type of powder, secured by leveling off the surplus powder after dipping the spoon in the can, have been about 3.0 grams for one brand of sulfate-phosphate, about 4.0 grams for a second brand, about 4.0 for the phosphate, and about 3.5 for the tartrate.

Of course, the optimum amount of baking powder, in addition to (*a*) the type of baking powder, varies with (*b*) the formula, (*c*) the thoroughness of creaming, (*d*) the method of mixing, (*e*) the extent of mixing, (*f*) the kind of flour used, (*g*) the technic of the operator, (*h*) time of adding the beaten egg white, (*i*) the altitude, and (*j*) the quality of the eggs.

In general, high-sugar-ratio formulas require slightly more baking powder than low-ratio ones. Thorough creaming of the fat and sugar, or fat, sugar, and eggs, lessens the amount of baking powder needed. Methods of mixing like the conventional sponge in which a great deal of air is incorporated in the egg-sugar mixture or when beaten egg whites are added last require less baking powder. Because of the tenacity of the gluten more baking powder is needed with bread or all-purpose flour than for pastry or cake flours.

That baking powder has an effect on the viscosity of the batter is shown clearly by adding varying amounts of baking powder (Experiment 57D) to a particular cake recipe. A much stiffer, thicker batter is secured with the larger quantity of baking powder.

Altitude. McCrittick (44) suggested reducing the baking powder by one-third at altitudes of 7200 feet for a one-egg cake. For richer cakes the butter is reduced one-sixth, sugar one-eighth, and baking powder one-fourth.

Peterson (55) showed that formulas for cakes and other products at sea level needed modification for use at high altitudes.

Barmore (10) continued the work at altitude to find the amounts of baking powder necessary to produce comparable cakes at different altitudes, using the A.A.C.C. cake formula. He found that the sugar ratio also needed varying to give excellent cakes. Formulas giving excellent results at sea level fell flat when baked at 10,000 feet unless the proportion of sugar in addition to that of the baking powder was decreased.

Loss of thiamine and baking powder. The eggs, milk, and flour (if enriched) of cake contain thiamine. Since added increments of baking powder increase the alkalinity of the batter, which increases the destruction of thiamine, it seems preferable to use as small amounts of baking powder as possible in cake recipes, to use methods of combining whereby more air is occluded in the batter and hence less baking powder is needed, and to use fruit juices or sour milk as the liquid in cake, at least for variation, which would tend to keep the reaction of the batter on the acid side.

Another possibility is that manufacturers might make baking powder with an excess of the acid salt.

pH. Stamberg and Bailey (63) find with a yellow layer cake (the composition of which, in percentage of flour used, is as follows: flour 100, shortening 50, sugar 125, frozen whole eggs 50, salt 3, baking powder 7, dry milk solids 15, and water and flavoring 87) that variation within limits in shortening, sugar, whole eggs, and water does not affect the *p*H appreciably. However, variation in the amount of baking powder affected the *p*H of both yellow and of white cakes more than any other common ingredient. When commercial phosphate baking powder was used at 6.5, 7.0, and 7.5% levels the *p*H values for the cake were 7.35, 7.74, and 7.91, respectively. Similar results were obtained with commercial tartrate baking powder. On the basis of flavor and eating quality, the optimum *p*H range of white and yellow layer cakes is 7.0 to 7.9. They state that this can be narrowed to *p*H 7.22 to 7.35. The average *p*H value of commercial cakes is: white, 7.47; yellow, 7.59; chocolate, 8.48; and angel, 5.67.

Fat. See the preceding sections for the distribution of fat in the batter and cake. The plasticity of the fat is important. A hard fat like tallow with a high melting point is not desirable in cakes. Even if creamed at sufficiently high temperatures so that the fat is plastic, on account of its hardness after the cake has cooled, it imparts a firm, crumbly texture.

Varying the proportion of fat. Increasing the fat results in a more tender cake. The fat in the plain cake recipe can be increased from ½ to ¾ cup and a good texture obtained, but the volume of the cake is smaller. With still greater increases of fat, the cake is more compact, the volume smaller, and the crumb soggy with fat. The crust of a cake with a large amount of fat appears rather smooth. It browns readily, but not so easily as with sugar.

By modifying the A.A.C.C. single-stage method of mixing, Pyke and Johnson (57) were able to obtain cakes of greater specific volume and desirability with ordinary hydrogenated shortening than with special hydrogenated shortening containing emulsifiers, even when the method of mixing was varied for the special shortening. The batters from special shortenings containing emulsifiers were always smoother and heavier than batters from ordinary hydrogenated shortening.

Sugar. As previously mentioned under creaming, the finer the granulation of the sugar, provided that it is a naturally formed crystal, the better the quality of the creamed mixture and the more desirable the cake. Brown sugar, because of its flavor, is often used in cake. It is preferable to substitute it by weight rather than by measure.

Varying the proportion of sugar. Sugar is added for sweetening. Also, with increase of sugar to the optimum amount the tenderness increases, the texture is improved, and there is less tendency to tunnel.

With large quantities of sugar the batter must be mixed longer even when baking powders that react rapidly at low temperatures are used. The sugar competes with the gluten and other ingredients for the liquid and prevents the development of the gluten so that longer mixing is necessary. When the sugar in the very plain cake recipe is increased from 1 to 1½ cups a sweeter cake is obtained and one with a better-balanced formula, so that texture and volume are improved. The amount of mixing to produce the best texture with 1½ cups of sugar is from 225 to 300 strokes when a tartrate or phosphate baking powder is used, if the powder is added with the flour. When the proportion of sugar is increased to 2 cups, Fig. 78, a decidedly different texture is obtained from that when the flour or egg is increased. With slight mixing the top of the cake is sunken or fallen; see Fig. 78, cake 1, mixed with 150 strokes, Experiment 57F, 4. Sometimes the cake bubbles up over the top of the pan and then falls. The top is rough, shiny, and has a crystalline appearance. The cell walls are very thick, and the cells are large and coarse. The cake browns readily. It is gummy and chewy when tasted. As the amount of mixing is increased the texture of the cake is improved. The number of strokes required to produce a fine grain is very much greater than in the plain cake. The texture with 1000 and 1500 strokes, cakes 5 and 6, Fig. 78, is very much better than in the cakes just slightly mixed. The most desirable texture is sometimes obtained with 400 strokes, sometimes with 1000, and occasionally with 1500. The cakes with increased sugar used in the illustrations were made with a tartrate baking powder.

Pyke and Johnson (57) have developed a nomograph from which, with an optional sugar content, formulas can be balanced for any selected altitude.

Honey. Honey is often used in cakes. Horton and Thursby (36) state that honey is substituted for sugar as follows: 1 cup of honey contains ¼ cup of liquid; deduct ¼ cup of liquid from the recipe when using honey; 1 cup of honey equals 1 cup of sugar in sweetening power.

Eggs. Since eggs vary in size, they should be weighed for experimental work. Pyke and Johnson (58) have shown that a highly significant correlation exists between the volume and tensile strength of cakes and the quality of the eggs. Fresh eggs from some hens consistently produce cakes of better volume than eggs from other hens. Deteriorated eggs or eggs of poorer quality as determined by the height of the thick albumen and yolk index give cakes of smaller volume than eggs of high quality. One factor in obtaining smaller volume is the elevation of coagulation temperature of the egg proteins with deterioration. With a high coagulation temperature the time the baking batter is held above the coagulation temperature of the egg protein is shortened. As a result the tensile strength is reduced and a lesser cake volume results. Eggs of poorer quality can be used more successfully at sea level than at higher altitudes.

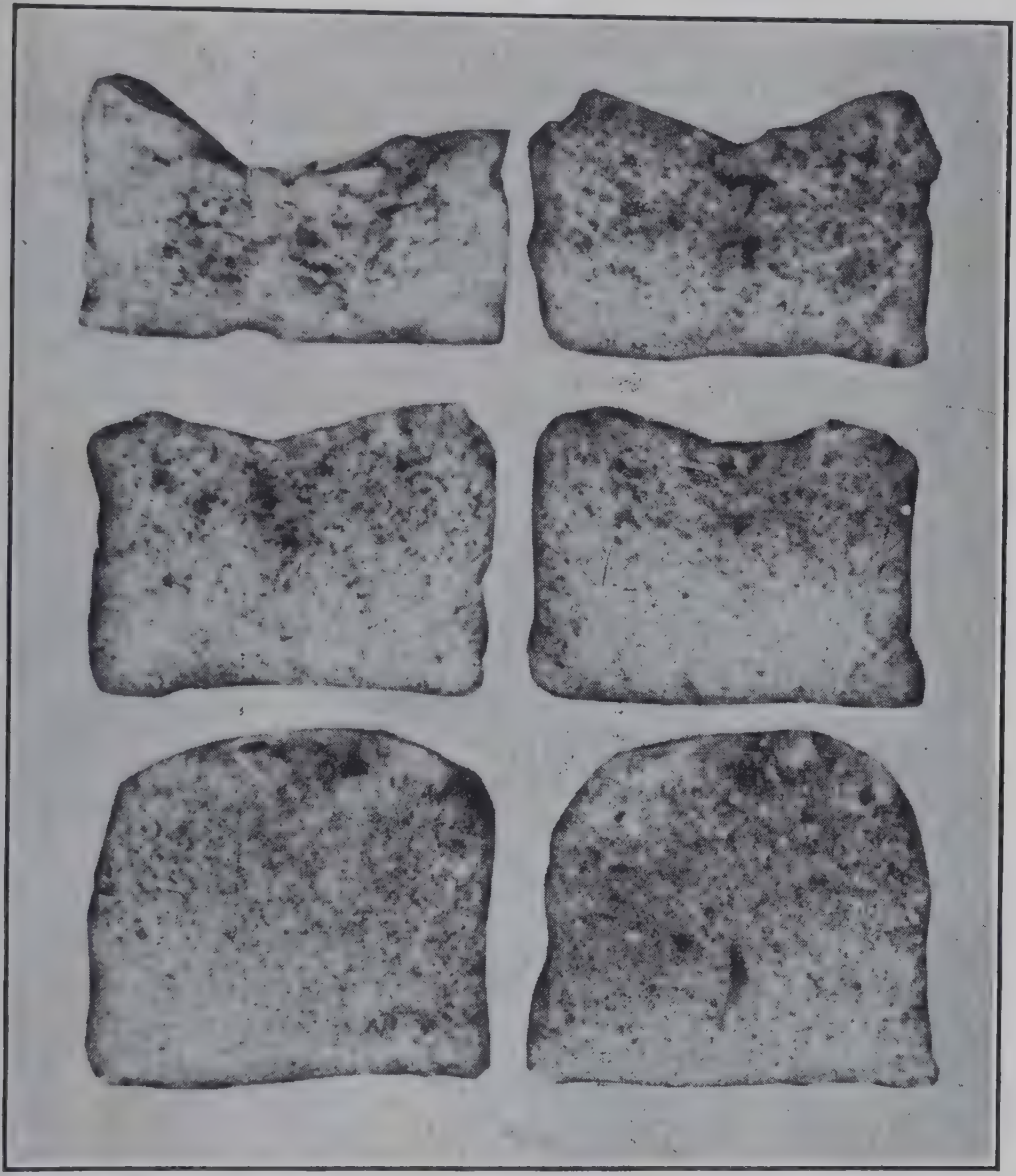


FIG. 78. Cake. Showing the effect on texture and volume of increasing the sugar in the plain cake recipe from 1 to 2 cups and varying the mixing. Experiment 57F.4.
Upper left: Mixed 150 strokes; *upper right:* 200 strokes.
Middle left: Mixed 300 strokes; *middle right:* 400 strokes.
Lower left: Mixed 1000 strokes; *lower right:* 1500 strokes.

Varying the proportion of egg. Egg cannot be increased beyond an optimum amount, unless sugar is increased at the same time, without detrimental results. The volume of the cake decreases, the crumb becomes very elastic, the cake more rubbery, tough, and compact, although the cells may be fine and the cell walls thin. Increasing the egg imparts a glaze to the crust, but the appearance is different from, and less crystalline than, that produced by increased sugar. Some improvement, but not much, is obtained if the egg white is beaten separately and added last.

Flour. Bohn (12) came to the conclusion that, for commercial pound-, sponge, layer, and angel cakes, the finer the flour, the better from a cake-baking standpoint. Patterson (53) also emphasizes the importance of uniform grinding of the flour for cake as flour particles of uniform size aid in obtaining uniform cells in cake. Shellenberger et al. (61) fractionated patent, straight, and clear grade flours, all milled from Ohio soft red winter wheat, into three sizes: 0–37 μ, 38–53 μ, and over 53 μ. The 0–37 μ fraction from each flour was the lowest in protein and ash and produced the best cakes.

Varying the proportion of flour. If the flour is very dry a better texture is obtained if it is reduced or the liquid increased. When the proportion of flour to other ingredients is increased, the tendency to tunnel is greater. The cake is drier and more solid, and is usually described as bready. The volume is good. When the flour in the plain cake recipe is increased to 3.5 cups, Experiment 57F, 7, the tenacity of the batter becomes very great. The gluten is developed in mixing. After mixing 1000 strokes ribbons of batter ¼–¾ inch in width and over a foot long will form when the batter is allowed to drop from the spoon.

Liquid. Water or fruit juices, such as orange, grapefruit, pineapple, and apple, may be used instead of milk in cake. In apple sauce and banana cakes the pulped fruit is used.

Milk solids. Hanning and de Goumois (34) prepared cakes, containing 20–40% fat and 100% sugar, with and without the addition of 15% dried edible whey. The addition of dried edible whey gave a more tender, soft, moist crumb than that of the control cakes. It also gave greater volume, improved flavor, and keeping quality. These investigators found that the fat could be reduced in the cake formula around 20–25% and be compensated for by the addition of 15% dry whey. One interesting result of the study was that dried whey produced cakes of better flavor and moistness than the non-fat milk solids.

Cake, Balancing of Formulas

Various ways and means are suggested for balancing cake formulas. The single variation of the plain recipe in the experimental outline that usually gives the most acceptable cake is to increase the sugar from 1 to 1½ cups. This recipe is formula I in Table 36.

Bakers have different rules for balancing cake formulas, but they state that there will always be exceptions to these rules. They also mix larger quantities in one batch than the housewife, 20–50 pounds or more at one time. It is well known that in large-quantity cookery the proportion of

TABLE 36

FORMULAS FOR PLAIN CAKE

Ingredients	Formula I		Formula II		Formula III		Formula IV	
	Measure	Weight, grams	Measure	Weight, grams	Measure	Weight, grams	Measure	Weight. grams
Butter	½ c	112	½ c	112	⅝ c	140	⅜ c	84
Sugar	1½ c	300	1½ c	300	1½ c	300	1½ c	300
Eggs	2	96	2	96	3	144	1½	72
Flour	3 c	300	3 c	300	3 c	300	3 c	300
Milk	1 c	244	⅚ c	204	⅝ c	156	1⅛ c	274
Baking powder	3 t	8–12	3 t	8–10	3 t	8–10	3½ t	10–14
Flavoring	1 t		1 t		1 t		1 t	
Salt	½ t		½ t		½ t		½ t	

liquid must be decreased, or if a very small portion of the recipe is made, the liquid must be increased. In many instances the rules given in bakery trade journals sift down to the following or similar suggestions.

1. The weight of the fat should not be over one-half the weight of the sugar.
2. The weight of the fat should not exceed the weight of the eggs.
3. The weight of the sugar should not exceed the weight of the flour.
4. The weight of the liquid (milk plus eggs, not weight of dried milk or eggs) should equal the weight of the flour.

Formula I, Table 36, is not a balanced recipe, if the bakers' rules for balancing are followed. However, for small-quantity mixing it usually produces a more palatable cake than formulas II and III. If two-thirds of the ingredients in formula IV are taken, one has a one-egg cake with ¼ cup of fat, 1 cup of sugar, etc., a formula in common use among housewives.

Chocolate Cake

Probably the question most often asked the author about chocolate cake is how to obtain a red one. This is usually countered by the query, "Why do you want a red chocolate cake?" The answer to this question is the color appeal. That the flavor might be better with a darker, less red color is not considered. However, to understand how to obtain a red color in chocolate cake it is necessary to know something of chocolate.

Chocolate. Chocolate is obtained from cacao beans of the cacao tree. The term cacao refers to the raw material until the press-cake stage. The term cocoa refers to the powder.

The cacao beans are cut from the pods, placed in piles, and fermented to reduce the bitterness of the chocolate. After fermentation the beans are roasted, then shelled and cracked. The cracked beans are called nibs. The roasting brings out the flavor, but Zenlea (79) states that the flavor of the chocolate is dependent upon skillful blending, milling, and conching of the various varieties of nibs with the proper quantity of sugar and cocoa butter, milk solids, when used, and added flavors. Approximately 30 varieties of cocoa beans are commonly used, and Zenlea says the nibs of these beans vary in color, chocolate character, pungency, acidity, mildness, bitterness, and creaminess. The blended nibs are ground, a temperature just above 32°C (90°F) being maintained during grinding, this temperature and the pressure rendering the product fluid. This chocolate liquor, which contains over 50% of cocoa butter, is run into molds and cooled for chocolate, forming the bitter chocolate for household and commercial uses.

The Food and Drug Administration (27*a*) gives definitions and standards of identity for various types of chocolate: (*a*) chocolate liquor, chocolate, or baking, bitter, cooking chocolate, (*b*) sweet, (*c*) milk, (*d*) skim milk, (*e*) buttermilk, (*f*) mixed dairy products, and (*g*) sweet chocolate and vegetable fat other than cacao fat. Chocolate or baking chocolate contains not less than 50% and not more than 58% by weight of cacao fat. Sweet chocolate contains sugar or a combination of sweetening ingredients, with or without spices.

The cocoa beans before being ground vary in color from a very light brown, or nearly gray, to a deep red brown. Thus the color of the chocoate or cocoa may vary because of the different colored beans from which it is made. A higher roast also gives a darker color. Alkali-treated chocolate is darker than natural-processed chocolate.

Bywaters (14) reports that the tannin group of substances is a very important constituent of cocoa matter, "for it determines to a great extent the colour and the taste of the product. Cacao catechin and cacao tannin are present in the unfermented bean." The catechin gives a very bitter flavor. Bywaters states that cacao tannin in the presence of oxygen is transformed into a phlobaphene, which is insoluble in water and reddish in color. The red color of cocoa is chiefly due to the presence of this phlobaphene.

To make cocoa the chocolate liquor is put in a hydraulic press and part of the cocoa butter is removed, leaving a cake containing less than one-half as much cocoa butter as the chocolate. This cake is pulverized.

Cocoa. Zenlea (78) states that there are many kinds of cocoas, but depending on processing they may be separated into two main classifications: (*a*) natural and (*b*) Dutch.

Natural-process cocoas have had no alkalies or "Dutching agents" added during manufacture. Schaal states that probably about 75% of the cocoas used by bakers are natural-processed cocoas. Some chocolate is also Dutch-processed.

Dutch-process cocoas have been treated with an alkaline solution such as potassium carbonate, ammonium bicarbonate, sodium carbonate, or hydrogen carbonate. In some instances, according to Zenlea, the cleaned nibs are actually boiled in an alkali solution as strong as 3%, on the basis of the weight of the nibs. In commercial practice 2% of alkali is more common. To complete the treatment, the water is evaporated and the Dutch nibs dried in a roaster. The nibs are then treated in the same manner as nibs for natural-process cocoas.

Bywaters states that the object of the Dutch process is to improve: (*i*) the flavor, (*ii*) the color, (*iii*) the solubility, and (*iv*) the digestibility. The proportion of cocoa that can be dissolved is less than 25%, even after treatment. The treatment darkens the color. Zenlea (78) states that natural cocoas have a *p*H value of 5.2 to 6.0; chocolate, 5.1 to 6.2; "Dutched" cocoas have a *p*H of 6.0 to 7.5; and chocolate, a *p*H 6.0 to 7.8. The reaction depends on the original *p*H of the nibs and the quantity and kind of alkali added.

Chocolate and cocoa contain some organic acids such as acetic and tartaric. The reaction of the cocoa determines the amount of soda that can be neutralized by the cocoa or chocolate in cooking. Less soda should be used with a Dutched cocoa in such products as cake and cookies, for the natural acidity of the cocoa has been lessened by the treatment.

Zenlea (78) describes several types of cocoa that may be used for various purposes. The Food and Drug Administration gives standards of identities for three cocoas: (*a*) breakfast cocoa, high fat cocoa, which contains not less than 22% of cacao fat; (*b*) cocoa, medium-fat cocoa, which contains less than 22% cacao fat, but not less than 10%; and (*c*) low-fat cocoa, which contains less than 10% cacao fat.

The less the fat content of the cocoa the more readily it absorbs moisture from the air and the greater is its thickening power when combined with water.

Zenlea declares the ideal temperature and humidity for storing cocoa to be 15.5–21.1°C (60–70°F) and 50–65 relative humidity. Heat, vibration, and moisture cause cocoa to lump and lose its color, which makes it more difficult to mix, though its quality may not be damaged.

Types of chocolate cake. Basing his classification upon the analysis of 952 home formulas, Schaal (60) divides chocolate cakes into devil's food, fudge, and chocolate. To this he adds a fourth cake seldom made by the housewife, milk chocolate cake. The differences in these cakes as shown by percentage of ingredients appear in Table 37.

Schaal lists the characteristics of the four cakes as follows: More soda is used with the devil's food cake, the amount decreasing in the order the cakes have been listed. The color varies from mahogany-, through chocolate-, cinnamon-, and mocha-brown for the four cakes. The texture of the devil's food is more open. The chocolate flavor varies from pronounced chocolate, chocolate fudge, true chocolate, to delicate milk chocolate.

The formula from the laboratory outline, Experiment 58A, differs decidedly from the four types given in the amount of shortening.

TABLE 37

TYPES OF CHOCOLATE CAKE AND THE PERCENTAGE OF INGREDIENTS IN EACH TYPE (*Schaal*)

Ingredients	Devil's food	Fudge	Chocolate	Milk chocolate	Formula Experiment 58A
Flour	15.1	15.0	17.6	17.9	19.44
Sugar	25.8	29.0	28.1	26.8	29.16
Shortening	11.4	9.8	8.4	8.6	14.52
Eggs (whole)	13.6	12.0	10.5	10.7	12.44
Cocoa (natural)	7.3	7.2			
Chocolate			8.4	4.5	7.32
Dry skim milk	3.0	3.0	3.0	9.0	
Liquid milk					15.81
Water	22.7	22.8	22.5	21.3	
Salt	0.55	0.56	0.68	0.65	0.26
Soda	0.55	0.19	0.16	0.12	
Baking powder		0.45	0.68	0.40	1.04

The color of chocolate cake. The factors influencing the color of devil's food and chocolate cake may be listed as follows, although factors other than those mentioned may also exert an effect.

Reaction. This is the most important factor in most formulas in producing a red mahogany-colored cake. The cakes having this color are alkaline in reaction. Schaal states that, when the *p*H of the finished cake batter is above 7.9, the soda taste is too pronounced and objectionable. To this the author heartily agrees. Schaal recommends that hot water and soda should not be mixed, or the soda combined with the chocolate and hot water, for leavening gas is lost and the cake color is a too "foxy" red. The soda, he says, may be creamed with the shortening and cocoa, it may be dissolved in the cold milk, or it may be mixed with the flour.

Chocolate has a slight acidity which will neutralize a small amount of soda, but many chocolate cake recipes call for an excess of soda, which gives an alkaline reaction. As the excess is increased, the soapy, bitter, alkaline flavor of the soda becomes more evident. Sweet milk and soda are likely to impart a deeper red or mahogany shade than sour milk and soda, for the acidity of the sour milk neutralizes a part or all of the alkalinity of the soda, the extent depending upon the amount of soda used. Soda, whether enough is used to give an alkaline reaction or not, always darkens the color; a lighter shade is obtained with baking powder. This darkening is probably due to the tannin constituents and the pigments or color constituents of the chocolate or cocoa.

Time. The length of time the batter containing soda stands before baking influences the color obtained. Batter which has stood 10–15 minutes—some cake bakers often permit it to stand while they bake a test portion—usually gives a deeper mahogany shade than a portion of the same batter baked immediately after mixing. These results have not always been consistent with different varieties of chocolate and cocoa but are obtained in a majority of the tests.

The quantity of chocolate or cocoa used influences the color, the shade becoming darker with increased amounts.

The brand of chocolate or cocoa. The reasons for variation in color with different brands of chocolate and cocoa have been indicated under their production. There is also a difference in the flavor of different brands of chocolate and cocoa.

The kind of baking powder used. It was a surprise to find that, when fat, sugar, eggs, and chocolate have been mixed together (Experiment 58B, 5), then divided, and a different type of baking powder used with each portion, the same shade is not obtained with all powders. The sulfate-phosphate powders always produce a darker brown, more nearly like that of gingerbread; the phosphate and tartrate types, a more reddish color.

But, after all, why try to develop the red color, especially that developed with a decided alkaline reaction, which is obtained only with an excess of soda? It has been the experience of the author that even students who like the reddish color prefer the flavor of chocolate cakes that do not contain an excess of soda. Since an excess of soda destroys the distinctive chocolate flavor, if cake is eaten for this flavor, a rich brown shade will be preferred to the mahogany one.

Addition of chocolate to cake batter. Cook (21) added chocolate at 30° and at 60°C to the creamed butter, sugar, salt, vanilla, and eggs, the creaming being continued 2 minutes after the addition of the chocolate. The temperature of the other ingredients at the start of creaming was 27°C. The volume of the cake was somewhat greater for the chocolate added at the higher temperature (see Fig. 64), but there was practically no difference in the total scores (see Fig. 65).

In balancing chocolate cake formulas, the weight of the chocolate or cocoa may be added to that of the flour. Both chocolate and cocoa increase the viscosity of unheated cake batters, probably owing to their dextrin content. The cacao beans contain starch. During their preparation part of this starch is dextrinized. The undextrinized starch thickens when heated.

Baking chocolate cake. The baking temperature has been considered. The statement that cakes and cookies containing chocolate should be baked at lower temperatures than plain cake or cookies does not appear to be supported by baking tests. Clark (66) found that the soggy layer at the bottom of chocolate cake could be overcome by elevating the baking temperature.

Gingerbread

To discuss the effect of manipulation and the kind and proportion of ingredients used in gingerbread would be repeating what has been considered under muffins and cakes.

Effect of alkali upon texture. Soda is used with the molasses or sorghum for leavening in gingerbread. Since soda is often added in excess, gingerbread offers an excellent opportunity for observing the effect of too much alkali upon the texture and the flavor of a batter.

The gluten also becomes more elastic and more extensible with alkalies. As the alkalinity is increased, the solubility or dispersion of the gluten increases more rapidly than on the acid side. Thus with an alkaline reaction the cell walls become more tender and collapse more quickly than with an acid reaction. This with the larger proportion of liquid gives the typical coarse structure of some gingerbreads and chocolate cakes.

With a large proportion of soda a hollow may form in the center of the gingerbread during baking. This is more likely to develop if the batter is allowed to stand a short time before baking. The soda causes partial dispersion of the gluten. The baking sets the crust, but the interior of the cake being baked last, the soda continues its action on the gluten during part of the baking with the result that the cake may be level across the top but have a hollow in the center. Sometimes the cake sinks across the top instead of forming the hollow in the center. With longer mixing and greater attenuation of the gluten the sinking does not occur.

The gingerbreads containing the largest proportion of soda are darker in color. This is due to several factors, *e.g.*, the effect of the soda on the color of the flour, the decomposition of the monosaccharids of the molasses by the soda, but principally to the color produced by the tannins of the molasses in an alkaline solution. The gingerbreads with baking powder and soda are lighter in color. The flavor of the gingerbread made with baking powder and no soda is different from that of gingerbread containing soda, particularly when a strong molasses is used, probably because soda combines with some of the ingredients of the molasses, thus producing a less strong flavor. With excess soda, its soapy, alkaline flavor is evident.

Prepared Mixes

The American Association of Cereal Chemists has sponsored symposiums on prepared mixes. Only a short discussion of mixes can be presented here, and all the topics covered in the symposiums cannot be mentioned. A list of the papers presented is given in the bibliography (3, 4). These papers cover various aspects of the ingredients used in prepared mixes. The discussion of each ingredient may include part or all of the following: statistics of production, types or variations in ingredients, methods of manufacture, differences in product when manufactured in different ways, special pretreatment for use in mixes, standards and tests of quality, stability of the ingredient, compatibility with other ingredients in the mix, storage life, packaging, and use. In most instances each writer discusses interrelations with other ingredients.

Classification of mixes. Mixes include (*a*) dessert mixes of various types, (*b*) miscellaneous mixes, and (*c*) prepared bake mixes. The last is discussed here. Prepared bake mixes have been classified in various ways as follows: according to the type of flour used, by the amount of shortening used, and by the means of leavening. Holton of Garnatz's panel (4*a*) says that both hard- and soft-wheat flours are used in doughnut and coffee cake. The amount of shortening is useful because it classifies somewhat the method of its use as well as the equipment and packaging required. However, he thinks the division by kind of leavening is the most useful. This division follows:

Leavening	Chemical	Yeast	Air	None
	Cake (shortening types)	Coffee cake	Angel cake	Pie crust
	Doughnuts	Raised doughnuts	Sponge	
	Pan cakes	Hot rolls		
	Waffles	Bread		
	Biscuits			
	Muffins			
	Cookies			

Storage life. A mix, like all other foods or ingredients, deteriorates with storage, this deterioration taking place faster at higher temperatures and when the humidity is high. Carpenter, Garnatz's panel (4*a*), says a mix should have a shelf-life expectancy of 15–18 months. He thinks trial packages should go through 2 summers in a hot humid city. The armed forces would like mixes to hold up 12 months at 100°F, preferably 24 months. Carpenter thinks the flour is often at fault in that mixes do not fill shelf-life expectancies. Carlin (3*d*) states that the following factors are most often mentioned in connection with deterioration of mixes: (*a*) the moisture content of the flour, (*b*) lipase action of the flour, (*c*) type of baking powder, (*d*) type of shortening, and (*e*) type of egg product.

Flour. Flour has a moisture content around 11–13%. With this amount of moisture, part of the leavening agent reacts and CO_2 is lost before the mix is prepared for baking. Other ingredients, such as eggs, have a longer shelf life if the moisture content is low, 1–2%. A large amount of moisture accelerates hydrolysis of the fat. The first attempt to dehydrate flour below 8% moisture injured the gluten qualities. McWilliams et al. (46) say that the moisture can be lowered to 2% by flash drying without injury to the baking quality. Mixes of low-moisture-content flours have less deterioration in storage. Low-moisture-content flour is not so important in yeast-leavened mixes. There is less deterioration of fat with unbleached flour. Other factors considered for flour are: cost, availability of blends or of certain flours, the chemical and physical characteristics needed in the particular mix. Low-grade flour is cheaper but also has more wheat germ. Granulation needs to be considered for mixes. The trend in all mixes is to use materials that will combine quickly with the liquid so that less energy needs to be expended by the user.

Shortening. The type of shortening (3*d*, 4*f*) best suited for pastry may not be the best for a cake mix. Since hydrogenated shortening made from soybean oil may "revert," *i.e.*, develop off flavors, its unqualified use is not recommended for mixes. Antioxidants are required. If moisture content of the mix is low and the baking powder is suitable, the fat often determines the shelf life of the mix. Ginger, cocoa, some spices, sugar, phosphates, lecithin, and dark molasses possess more or less antioxidant properties. Some spices are pro-oxidant.

Leavening. The acid ingredient of baking powder (3*c*, 4*g*) used in mixes is usually sodium acid pyrophosphate, although anhydrous monocalcium phosphate is also used. Sodium aluminum sulfate is not used as it hastens rancidity and has a tightening effect on the gluten of the flour. Baking powder can be tailored to slow its rate of solution by increasing the particle size or by coating the particles. Sodium acid pyrophosphate can be manufactured for doughnuts with a 1.5-minute cooking cycle or for cakes with a 15-minute baking cycle.

Milk. Non-fat dry milk solids (3*b*, 4*b*) are used instead of whole milk solids as the former has better keeping quality. Spray-dried milk solids are more soluble than roller-dried ones.

Eggs. Egg yolks (3*a*, 4*e*) are largely used in doughnuts and sweet dough mixes. Dried whites are used in white layer, devil's food, and angel cake mixes. Dried whole eggs have been used to a lesser extent. Wherry and Tinklin (74) have shown that a prepared cake mix containing dried whole egg holds its top quality only about 7 weeks at room temperature, 20 weeks when refrigerated. Although the stability of whole egg has been improved, it still does not hold its quality as long as desired in a mix. It is for this reason that egg is not included in some cake mixes. As egg deteriorates, whether white, yolk, or whole, it loses its solubility, thus its whipping and thickening functions, in addition to flavor deterioration.

Antioxidants. Some antioxidants (3*d*), because of the shelf life of the mix, cannot be used in mixes. Gum guaiac turns purple in the presence of peroxidase. Flour contains peroxidase and catalase. The peroxidase may be inhibited or destroyed if the flour is heated. Propyl gallate turns green in the presence of egg yolk, and if exposed simultaneously to iron rust and moisture it turns black. Acidification tends to inhibit the color changes of the antioxidants.

Directions for use. Most mixes have excellent directions for their use.

Advantage to user. A mix should offer the user: (*a*) economy of time in preparation and possibly storage space, (*b*) an acceptable, palatable product, (*c*) nutritive value comparable to a homemade product, and (*d*) cost that should compare favorably with the homemade product. Sometimes the cost is more than the homemade, sometimes less. This depends on the ingredients used and the variation in cost of ingredients at different seasons.

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BATTERS AND DOUGHS

I. Thin Batters

Popovers

Experiment 52.

To determine the factors that affect the texture of popovers.

Recipe:

Milk	1 cup	244 grams	Flour	1 cup	112 grams
Eggs	2	96 grams	Salt	½ teaspoon	
Fat	1 tablespoon	12 grams			

A. Batter just mixed.

Prepare ¾ of the recipe. Mix only enough to free from lumps. Bake the popovers in deep cups of the same size, shape, and material. Grease the cups on the bottom, but only lightly on the sides. Fill the cups ⅓ full. Use 3 cups, and weigh 40 grams of batter into each cup. Bake one at 180–190°C (355–375°F), one at 220–225°C (425–435°F), and the third at 240–250°C (465–480°F). Save the remaining batter for part B.

B. Batter thoroughly beaten.

Beat the batter remaining from A vigorously for 3 minutes. Divide into three parts, using 40 grams of batter in each cup. Bake at temperatures given under A.

C. Variations in proportions of ingredients.

Prepare ¼ the recipe. Use 40 grams of batter in each cup. Bake at the temperature found best under A and B.

1. Reduce the flour in the recipe to ⅞ cup.
2. Reduce the flour in the recipe to ¾ cup.
3. Omit the egg in the recipe.
4. Increase the eggs in the recipe to 3.

Considering the volume, size of the cavity, the appearance, and the texture, does the beating of the batter produce a better popover? Which proportion of flour gives the best popover? Which is the best temperature for baking? Does the egg serve as a liquid or as a thickening agent? What effect does the egg have on the "lightness" of the popover? Does it serve as a leavening agent or does it hold the shape after the popover is leavened by something else? What is the means of leavening? Can the egg be omitted? Which proportion of egg is best?

Cream Puffs

Experiment 53.

To determine the factors that influence the texture of cream puffs.

Recipe:

Butter	½ cup	112 grams	Eggs	4	192 grams
Boiling water	1 cup	240 grams	Flour	1 cup	112 grams

A. Temperature of baking.

Prepare ¼ of the recipe. To the boiling water add the butter; then the flour. Stir while adding the flour and cook until the material has a tendency to form a ball and leave the sides of the pan. The paste is done when a metal spoon pressed down lightly leaves a clear, smooth print. Remove from the fire and add the beaten eggs in two portions. Beat thoroughly after adding the first half of the egg and until smooth and even in texture after the second half is added. One-fourth the recipe makes 3 fairly large puffs. Drop on baking sheets and bake at the following temperatures: 190–200°C (375–390°F), 220–225°C (425–435°F), and 240–250°C (465–480°F). Bake until the puffs are quite firm to the touch. After the puffs become brown, lower the two higher oven temperatures, and finally turn off the heat and let set in the oven to partially dry the interior.

B. Variation in the amount of cooking before the eggs are added.

1. Prepare ½ the recipe. Cook the butter, the flour, and the water together until the emulsion begins to break and the mixture looks oily on the surface. Remove from fire. Weigh, and divide into 2 equal parts. To one part add eggs for ¼ the recipe. Use the other part for B2. Follow directions under A for baking and cooking, or bake all the puffs at the temperature under A that gave the best product.

2. Before removing from the fire add enough boiling water to give a smooth mixture and one that does not look oily. Keep a record of the amount of water added. Remove from the stove and add eggs.

C. Variation in extent of mixing the egg with the cooked paste.

Weigh flour, fat, and water for ¾ the recipe and cook. After it is cooked weigh and divide into 3 equal parts. Follow directions under A for combining and the temperature of baking found best under A.

1. To part one add beaten egg for ¼ the recipe, and mix only slightly with the paste. This makes 3 puffs. Note behavior of fat in the puffs while baking.

2. To part two add beaten egg for ¼ the recipe. Add the egg in two portions, and beat thoroughly until very smooth and shiny.

3. Repeat C2, but cool the paste before adding the egg.

D. Variations in the proportions of ingredients.

Prepare ¼ the recipe.

1. Omit the eggs in the recipe.
2. Reduce the number of eggs in the recipe to 3.
3. Reduce the eggs in the recipe to 3, and increase the water to 1¼ cups.
4. Reduce the eggs in the recipe to 3, and reduce the fat to ¼ cup.
5. Reduce the fat in the recipe to ¼ cup.

Which is the best temperature for baking cream puffs? How much water was added in B2? What is the effect on volume of puffs of only slightly mixing the eggs with the paste? Can the eggs be omitted? Does the emulsion hold when the eggs are reduced to 3, or does the fat ooze out of the cream puffs while they are baking in the oven? Is there a tendency for the fat to be retained better when the eggs are reduced to 3 if the water is increased? Is the texture desirable when the water is increased? Does the emulsion hold in baking when both the fat and the egg are reduced? Is a good volume attained with reduced fat and egg? If water, flour, and fat are overcooked, how may this be remedied?

Medium Batters

Waffles and Griddle Cakes

Experiment 54.

To determine when baking powder should be added to a batter.

I. To determine the factors that affect the texture, tenderness, and flavor of waffles.

Recipe for plain waffles:

Milk	1 cup	244 grams
Eggs	2	96 grams
Flour	1 to 1½ cups	112 to 168 grams
Oil or melted fat	2 tablespoons	25 grams
Salt	½ teaspoon	
Baking powder	0 to 1½ teaspoons	0 to 6 grams

Sift the flour and baking powder together twice. Separate the yolk and white of the egg. It will be necessary to beat at least a whole white or yolk; then divide it. Mix the fat, beaten yolk, salt, and milk. Combine with the flour, stirring only until well blended. Count the strokes used for combining. Beat the egg white until stiff, and stir into the batter with 20 strokes. Use the same kind of baking powder for all the experiments until section C is reached. The amount of ingredients given under each experiment is for the full recipe. Most waffle irons, if divided into 4 sections, require ¼ of the recipe to fill the iron.

Heat the waffle iron. Test the temperature, if the iron does not have a temperature indicator, by placing a drop of water on the iron. If the drop boils rapidly the iron is hot enough. If the drops boils so vigorously that it vaporizes very rapidly, the iron is too hot. It is better to have the waffle irons of the same make and type for some experiments so that the depth of the batter will be the same for all waffles. Put the baked waffles on cake coolers until comparisons are made. Putting the baked waffles on plates causes the under side to sweat and become soggy. To keep warm, place wire cake cooler with waffle in slightly warmed oven.

A. The time of baking waffles.

1. Prepare ¾ of the recipe. Use 1⅓ cups of flour (150 grams), and 4 grams, about 1 teaspoon, of baking powder. Bake one waffle 3 minutes, one 4 minutes, and one 5 minutes. The time may need to be varied depending on the temperature maintained by the iron. Compare for crispness and tenderness.

B. Proportion of ingredients.

Prepare ¼ of the recipe. Use time of baking found best under A for a guide. Will the thin batters under 1 and 2 require a longer time than the thick ones? Apply results with popovers and cream puffs.

1. Use 1 cup flour and 4 grams of baking powder.
2. Repeat 1, but increase the flour to 1½ cups.

C. Kind and amount of baking powder.

Prepare ¼ the recipe. Use 1⅓ cups of flour and 4 grams of baking powder. Bake all waffles under C in the same iron and for the same period of time.

1. Use a tartrate baking powder.
2. Use a phosphate baking powder.
3. Use a sulfate-phosphate powder.
4. Determine the most desirable quantity of each baking powder for the proportion of flour preferred.

D. Extent of mixing.

1. Prepare ¼ the recipe, using the proportion of flour found best under B. Use 60 strokes for combining the flour and liquid. Add the beaten egg white, keeping a record of the number of folds.
2. Repeat D1, but use 120 strokes for mixing the flour and liquid and same number of strokes for folding egg white as under D1.

What length of time of baking gives the best waffle? Does crispness depend upon the length of time of baking or proportion of ingredients or both? Which proportion of flour do you prefer for a plain waffle? Is there any difference in the waffles made with the various types of baking powders? Should the quantity of baking powder be varied for each type of powder? What is the effect of mixing the batter too long on the texture and tenderness of the waffle? May the length of time of mixing vary with the different proportions of flour?

Griddle Cakes

II. To determine the factors that affect the texture, tenderness, and flavor of griddle cakes, but particularly the effect of varying the amount of baking powder.

Recipe:

Milk	1 cup	244 grams
Egg	1	48 grams
Fat, melted	2 tablespoons	25 grams
Flour	1⅓ to 1⅔ cups	150 to 186 grams
Salt	½ teaspoon	2 grams
Baking powder	About 1 to 2 teaspoons	4 to 8 grams

Prepare ¼ the recipe. Use the baking powder indicated for experiments under A. Test the heat of the griddle by baking 1 tablespoon of the batter. It should be possible to bake the cake without addition of fat to griddle. Sift flour and baking powder together twice. Mix the well-beaten egg, milk, melted fat, and salt. Combine with flour, stirring 50 times.

A. The proportion of baking powder. (Amounts given are for the entire recipe.)

1. Use 1⅓ cups of flour and 4 grams of a tartrate baking powder.
2. Repeat A1, using 6 grams of a tartrate powder.

3. Repeat A1, using 8 grams of a tartrate powder.
4. Repeat A1, using a phosphate baking powder.
5. Repeat A2, using a phosphate baking powder.
6. Repeat A3, using a phosphate baking powder.
7. Repeat A1, using sulfate-phosphate (S.-P.) baking powder.
8. Repeat A2, using S.-P. powder.
9. Repeat A3, using S.-P. powder.

B. The amount of mixing.

Repeat A1, 2, and 3 (or any third of A), but mix 120 strokes.

C. The proportion of flour.

1. Use 1¼ cups of flour and proportion of baking powder found best under A.
2. Repeat C1, using 1⅓ cups of flour.
3. Repeat C1, using 1½ cups of flour.

D. Using sour milk.

Repeat section C, but substitute sour milk for the sweet. Use 2 grams of soda but no baking powder.

E. Dried egg.

Repeat section C, using dried egg. On the basis of egg solids, about 12 grams of dried whole egg and 36 grams of water will reconstitute the egg. The dry egg powder may be sifted with the flour and the extra water added to the liquid, or the water may be added gradually to the dry egg powder, making paste. Then combine with milk.

Compare the griddle cakes for texture, tenderness, and lightness. Which proportion of baking powder produces the lightest product? Should the amount of baking powder be varied for the different types of baking powder? Which proportion of flour gives the best griddle cake with sweet milk? With sour milk?

When should baking powder be added to a batter? Compare the amount of baking powder needed for waffles and griddle cakes.

Stiff Batters

Muffins

Experiment 55.

To determine the factors which affect the texture of muffins and the amount of mixing required with different types of baking powders.

Recipe:

Flour	2 cups	224 grams
Sugar	2 tablespoons	25 grams
Milk	1 cup	244 grams
Egg	1	48 grams
Fat, melted or oil	2 tablespoons	25 grams
Baking powder		12 grams
Salt	½ teaspoon	2 grams

Directions for combining.

Combine the milk, beaten egg, and melted fat. Since the batter is mixed very little after the dry ingredients are added, it is better to beat the egg enough so that it readily combines with the milk, or beat both egg and milk with the egg beater. Sift the baking powder with the flour twice. Mix the sugar and salt with the flour. Combine with the liquid ingredients, stirring the amount indicated in the following experiments. Bake the muffins in cups of the same size and the same material. The sides of the cups do not need greasing, but the bottoms should be well greased to facilitate removal of the muffins from the tins. Decrease the baking powder to 10 or less grams, or increase to 14 or 16 grams, depending on the type of flour used and the altitude.

A. To determine the effect of the amount of mixing upon the texture and volume of muffins.

1. Prepare ½ the recipe. Use a tartrate baking powder. Notice the way in which the batter changes while mixing. Describe this change. Compare the volume of the batters for each muffin. Does the same weight of batter give the same volume after mixing different amounts?

Stir the batter. Combine with 25 strokes. For a medium-sized pan remove 60 grams of batter for one muffin. Stir the remaining batter a total of 60 strokes. Remove 60 grams for another muffin. Stir the remaining batter a total of 100 strokes. Remove 60 grams for a third muffin. Beat the remaining batter a total of 300 strokes, and use 60 grams for the fourth muffin. Bake at 210°C (410°F).

2. Repeat A1, but use a phosphate baking powder.

3. Repeat A1, but use S.-P. powder.

B. To determine the amount of mixing that gives a muffin of the best flavor, tenderness, texture, and volume.

1. Prepare ½ of the recipe. Use a tartrate baking powder. Stir a total of 25 strokes. Remove 60 grams of batter for one muffin. Stir the remaining batter a total of 30 strokes. Remove 60 grams of batter for a second muffin. Stir the remaining batter a total of 35 strokes. Remove 60 grams of batter for a third muffin. Stir the remaining batter a total of 40 strokes, and bake 60 grams for a fourth muffin.

2. Repeat B1, but use a phosphate baking powder.

3. Repeat B1, but use S.-P. baking powder.

C. Varying the proportion of baking powder.

1. Repeat either or all of B1, B2, and B3, reducing the baking powder to 10 grams.

2. Repeat either or all of B1, B2, and B3, increasing the baking powder to 16 grams.

D. Dried egg.

1. Use 12 grams of dried whole egg, sifting it with the flour and increasing the liquid by 36 grams.

2. Use 12 grams of dried whole egg. Add 36 grams of water or milk gradually to the egg powder.

E. Variations in proportion of ingredients.

Use a tartrate baking powder, and prepare ¼ of the recipe. Mix with the number of strokes found best under B. Weigh 60 grams of batter into a baking cup. Beat the remaining batter 10 additional strokes. Bake 60 grams. If desired, the series may be repeated with phosphate and S.-P. powders.

1. Use the regular recipe for a control.

2. Increase the fat in the recipe to 3 tablespoons.

3. Increase the sugar in the recipe to 3 tablespoons.
4. Increase the fat to 3 tablespoons and the sugar to 3 tablespoons.
5. Increase the egg in the recipe to 2.
6. Omit the egg in the recipe.

Does variation of the proportion of the ingredients influence the amount of mixing required for the muffins? Which proportion of ingredients gives a muffin of the most desirable texture, flavor, and volume?

Doughs

Baking-Powder Biscuits

Experiment 56.

To determine the factors that influence the texture of baking powder biscuits.

Recipe:

Flour	2⅔ cups	300.0 grams
Fat	4 tablespoons	50.0 grams
Milk	¾ to 1 cup	188.0 to 244 grams
Baking powder		12 grams
Salt	½ teaspoon	2 grams

Directions for combining.

Sift the baking powder with the flour. Add the fat and the salt. The fat may be combined with the flour by a fat-flour blender or by using the tips of the fingers. Portions of the fat and flour are picked up and rubbed quickly between the fingers, then dropped and other portions of the flour picked up. The lifting of the portions of the flour and fat mixture makes it more light and fluffy. Avoid mixing until a hard fat is melted and the mixture looks oily and compact. After the fat is mixed with the flour, form a cavity in the center of the flour mixture. Pour the milk in this cavity and begin to stir. The stirring may be done with a fork or a spoon. The following directions are for mixing with a three-tined fork, as the fork seems to leave the dough lighter and more fluffy than a spoon. After the milk has been mixed for the designated amount with the flour mixture, remove the ball of dough from the mixing bowl with a spatula and place it on a thin layer of flour on a bread board. Handle the dough gently, and roll it without compressing it in the flour, until the sticky surface is covered. Remove to a lightly floured part of the bread board. "Lightly floured" means with a very thin layer of flour. Knead the dough gently the amount specified, and place an embroidery hoop over the dough. Roll, and then cut with biscuit cutters of the same size for all the experiments. The embroidery hoop is used so that the biscuit dough will be the same thickness and the volume of the biscuits can be compared. Bake at 220–230°C (425–455°F). The dough, instead of being kneaded, can be lightly flattened into a square. Fold once and roll. Repeat 3 more times.

A. To determine the best proportion of liquid for the flour used in this experiment.

Brand of flour used:

The flours most often used in some sections of the United States are from soft-wheat flours. Other sections use bread flour. Since the proportion of liquid that gives the best flavor, texture, and the tenderest biscuit varies with different flours, it will be necessary to determine this first.

Prepare the full recipe. After the fat has been mixed with the flour, divide into four portions, using 87 grams in each part.

1. To part one add 61 grams of milk. The water of the milk is equivalent to about 70% of the weight of the flour. Stir 30 strokes with a three-tined fork. By this time the dough should be in a ball. Remove the dough with a spatula, roll in flour, and knead 10 times. Roll and cut.
2. Repeat 1, but to part two add 55 grams of milk, about 64% of liquid.
3. Repeat 1, but to part three add 51 grams of milk, about 60%.
4. Repeat 1, but to part four add 47 grams of milk, about 55% of liquid.

B. To determine the amount of mixing to give a rolled biscuit of the best volume and texture.

1. Prepare ½ the recipe, using the proportion of milk found best under A. Mix 20 strokes with a three-tined fork. Remove ⅓ of the dough and knead 10 times. Roll and cut.
2. Stir the remaining dough a total of 30 times. Remove ½ of the dough and knead 10 times. Roll and cut.
3. Stir the remaining dough a total of 40 strokes. Knead 10 times. Roll and cut.

C. The amount of kneading.

1. Prepare ½ the recipe, using the proportion of milk found best under A. Mix 30 strokes with a three-tined fork. Remove to the bread board. Divide into thirds. Knead ⅓ of the dough lightly 10 times, place an embroidery hoop over the dough, roll, and cut.
2. Knead the second third of the dough 20 times, roll, and cut.
3. Knead the last third of the dough 30 times, roll, and cut.

D. To determine the proportion of fat that gives a biscuit of the best flavor and texture.

1. Prepare ¼ of the recipe. Use the proportion of milk found best under A and the amount of mixing found best under B and C.
2. Repeat D1, but decrease the fat to 37.5 grams for the full recipe.
3. Repeat D1, but increase the fat to 75 grams for the full recipe.

Section D can be repeated with fats like butter, lard, hydrogenated cottonseed oil, hydrogenated lard, and oil. For butter reduce the amount of salt in the recipe by half.

E. To determine the best baking temperature when different types of baking powders are used.

1. Prepare ¼ the recipe. Use the proportions of milk found best under A, and the amount of mixing found best under B and C. Use a tartrate baking powder. Divide the dough into three biscuits, and bake one at 190–195°C (375–385°F), one at 220–225°C (425–435°F), and one at 240–250°C (465–480°F).
2. Repeat E1, using a phosphate baking powder.
3. Repeat E1, using a S.-P. baking powder.

Which proportion of milk gives the best volume and the best texture? Would this be the best proportion for all kinds and grades of flour? Why? Might there be slight differences in the hydration capacity of the same flour at various times of the year? Why? Should you use more or less water in biscuits to produce the same result when water is substituted for milk? Why? What amount of mixing gives the best texture with each baking powder? What is the effect of kneading upon the texture? Is it desirable? What amount of kneading and stirring gives the best texture for the flour you are using? Which proportion of fat produces the best flavor and texture? If the amount of fat in the recipe is increased, should the liquid be increased or decreased? Do you find much difference in the baking temperatures required for the different baking powders? Theoretically, which temperature should be best for each powder?

Suggestions for Additional Experiments for Biscuits

1. Repeat A, B, and E with a different type of flour, *e.g.,* soft- instead of hard-wheat, or *vice versa;* whole-wheat or part whole-wheat and part white flour.
2. Repeat A, B, and E with sour milk or water.
3. Use the different types of baking powders, and hold biscuits in the refrigerator for several hours before baking.
4. Increase the baking powder in the recipe to 14, 16, or 18 grams. Does it improve the texture? The flavor?

Plain Cake

Experiment 57.

To determine the factors that affect the texture and flavor of plain cake.

The following formula is not considered a standard cake recipe. For standard recipes see Table 36.

Plain cake recipe:

Fat	½ cup	112 grams	All-purpose	2⅔ cups	300 grams
Sugar	1 cup	200 grams	or		
Eggs	2	96 grams	Cake flour	3 cups	300 grams
Milk	1 cup	244 grams	Baking powder		10 grams
			Salt	½ teaspoon	2 grams

Pastry or soft-wheat flour may be used instead of the all-purpose hard-wheat flour. Flavoring is added during creaming for home use, but may be omitted for experimental work. Stirring is going round and round the mixing bowl, either rapidly or slowly; beating is pulling the utensil across the contents of the mixing bowl. The directions for all the mixing are for stirring. If the class decides to beat the batter instead of stirring, this should be understood before starting the mixing so that all will use uniform methods. Bake at 185°C (365°F).

A. To determine the amount of mixing that gives the best texture for a plain cake with different types of baking powders.

1. Use a tartrate baking powder.

Pans. Pans 5 by 2½ by 2½ inches, and 2 cups' capacity, are a good size for ⅙ of the above recipe. If larger or smaller pans are used, prepare the proportion of the recipe needed for the size of the pan. Muffin pans may be used. If they are medium size and 60 grams of batter are taken for each cake, only ½ of the recipe should be prepared. Line the bottom of the pan with wax or heavy plain paper. Grease the paper on the side next to the batter. The sides of the pan do not need greasing.

Prepare the whole recipe. Sift the baking powder with the flour twice. It can be sifted on squares of paper or in bowls. It is preferable to have incubated the ingredients or put them in the room previous to starting work so that their temperature is about 25–27°C. If this is not possible, place the fat over warm, not hot, water and stir while softening it. Since the fat alone does not hold much air when stirred or creamed but does hold air after the sugar is added, some sugar should be added at the start of the creaming process. If creaming is done on a machine, add all the sugar to the fat at first, in order to standardize the procedure. Creaming is more rapid when done by hand, if the sugar is added gradually. Cream until light and fluffy. Add the well-beaten eggs, and mix thoroughly. Add all the flour and all the milk to the butter mixture. Begin to stir; notice any changes that occur in the batter while stirring. Stir 50 strokes. Remove 150 grams of the batter and weigh into a cake pan. Note the position of the batter that drops from the edge of the spoon in relation to the pan in the last cakes. Do any tunnels develop at these spots in the cakes?

2. Stir the batter remaining from 1 a total of 150 strokes. Notice any changes in the batter. Use 150 grams of batter for the second cake.

3. Stir the batter remaining from 2 a total of 200 strokes. Note any changes in the batter. Use 150 grams of batter for the third cake.

4. Stir the batter remaining from 3 a total of 300 strokes. Remove 150 grams of batter for the fourth cake.

5. Stir the batter remaining from 4 a total of 400 strokes. Note any changes in the batter. Bake 150 grams of the batter.

6. Stir the batter remaining from 5 a total of 1000 strokes. Note any changes that occur in the batter. Use 150 grams of batter for a sixth cake.

B. Repeat A, using a phosphate baking powder.

Brand of baking powder used:

C. Repeat A, using S.-P. baking powder.

Brand of baking powder used:

A, B, and C. What is a desirable amount of mixing for each type of baking powder for a very plain cake? With which baking powder can the most mixing be used? With which can the least be used? Describe the way in which the batter changes during the mixing. Does it vary with the different baking powders? How long are the strands of batter that fall from the spoon during the different stages of mixing?

D. To determine the optimum amount of baking powder.

Prepare ⅙ or ¼ the recipe according to the size of the baking pan used. Increase the sugar to 1½ cups. For ⅙ the recipe bake 150 grams of batter, for ¼, 235 grams. Add the flour by method *a, b,* or *c,* but use only one method throughout the experiment. Use 225 strokes for combining the flour and milk with the creamed mixture.

All the fat, sugar, and eggs for one section can be creamed together thoroughly and divided into 6 equal parts.

Method a for adding flour. (Flour first and last.)

Add approximately ⅓ of the flour, and stir 50 strokes. Add ½ of the milk, and stir 25 additional strokes or a total of 75. Add another third of the flour, and stir a total of 125 strokes. Add ½ of the milk, and stir a total of 150 strokes. Add the remainder of the flour, and stir a total of 225 strokes.

Method b for adding the flour.

Add approximately ⅓ of the flour and ⅓ of the milk. Stir 75 strokes. Add another ⅓ of the flour and ⅓ of the milk, and stir a total of 150 strokes. Add rest of flour and milk, and stir a total of 225 strokes.

Method c for adding flour. (Milk first and last.)

Add ⅔ of the milk to the creamed mixture, and stir 5 strokes. Add all the flour, and stir a total of 175 strokes. Add the remainder of the milk, and stir a total of 225 strokes.

a. Use a tartrate baking powder.

1. Use 6 grams of baking powder for the full recipe.
2. Use 8 grams of baking powder for the full recipe.
3. Use 10 grams of baking powder for the full recipe.
4. Use 12 grams of baking powder for the full recipe.
5. Use 14 grams of baking powder for the full recipe.
6. Use 16 grams of baking powder for the full recipe.

b. Repeat section D*a,* using a phosphate baking powder.

c. Repeat section D*a,* using an S.-P. baking powder.

Which amount of powder produces the best-textured cake with a tartrate, phosphate, and S.-P. baking powder, respectively? Do all members of the class agree on which amount is preferable? Might the optimum amount vary with the maker's technic? With other factors? Enumerate. What is the effect on volume, texture, velvetiness, and crumbliness of cake of a small amount of powder? Of the large amounts? Which amounts of baking powder yield cakes that stale rapidly?

E. To determine the effect of varying the temperature of baking and the method of combining ingredients for a plain cake.

Prepare ¼ or the proportion of recipe desired. Increase the sugar to 1½ cups. Use 225 strokes for combining the flour and milk with the creamed mixture. For ¼ the recipe, 235 grams of batter should be weighed into the baking pan; for ⅙, use 150 grams. Use the proportion of baking powder found best under D, but use the same kind of powder for all of section E.

1. Conventional method. Cream enough butter, sugar, and eggs for 3 cakes. Add the sugar gradually to the butter, and cream thoroughly. Add the beaten egg, and mix until light and fluffy. Divide into 3 equal parts. If using ¼ the recipe, weigh out 124 grams for each cake unless a smaller amount is necessary to divide the creamed mixture evenly.

1*a.* To part 1 of the creamed mixture add the flour by method *a* given under D.

1*b.* To the second part add the flour by method *b* under D.

1*c.* To the third part add the flour by method *c* under D.

2. Muffin method. Sift the baking powder and the flour together twice. Use melted fat. Beat the egg. Combine the liquid ingredients. Add dry ingredients to the liquid ones, and mix 225 strokes.

3. Separating the yolk and white of the egg. Prepare ¾ or proportion of recipe desired. Separate the white and yolk of the egg. Cream the fat and sugar thoroughly. Add the yolks to the creamed fat, and mix until light and spongy. Sift the baking powder and flour together twice. Add the flour and milk according to method *c* under section D, but stir only a total of 160 strokes

after adding the flour and 195 after adding the last of the milk. Add the beaten egg white, and fold 30 strokes with a spatula, or stir with a spoon. Divide into 3 cakes, using equal weights of batter for each. Bake one at 185°C (365°F), the second at a lower temperature, and the third at a higher temperature.

4. Modified method. Cream fat, sugar, and egg for 3 cakes. Have the fat room temperature or about 25°C. Add the sugar and well-beaten egg, and cream until very light and spongy. Sift the flour and baking powder together twice. Divide the creamed mixture into 3 equal parts.

4*a*. To part 1 of the creamed mixture add the flour by method *a* under section D.

4*b*. To part 2 add the flour by method *b* under section D.

4*c*. To part 3 add the flour by method *c* under section D.

5. Emulsion method. Beat the egg slightly. Melt the fat carefully so that it does not reach a high temperature. Add a few drops of the melted fat to the egg and beat with an egg beater. After the emulsion is started add more fat. The fat is added to the egg in the same manner as in making mayonnaise. After the fat is added to the egg add the sugar gradually. Sift the baking powder and flour together twice. Add the flour and milk by method *a, b,* or *c* under section D.

6. Conventional sponge. Prepare ¼ or proportion of recipe desired. Cream ½ of the sugar and fat thoroughly. Add a tablespoon of flour, with which the baking powder has been sifted twice, and fold 20 times. Add ½ of the remaining flour and ½ of the milk, and stir 75 additional strokes or a total of 95. Repeat, adding the rest of the flour and milk. Total strokes 170. Beat the egg, adding the remaining sugar gradually, until mixture is very light and looks like sponge cake batter. Combine quickly with the cake batter, using 55 strokes, making a total of 225 strokes after starting to add the flour.

7. Use an oil or soft fat. A better texture is obtained with an oil if the egg goes into the cake batter late in the mixing process. Increase the salt to 4 grams for fat other than butter.

a. Use the conventional method for a control.

b. Combine the egg thoroughly with the milk.

c. Add the egg yolk to the milk. Reserve ¼ of the sugar. Beat the egg white until foamy, then add the reserved sugar. Add egg-white meringue to batter last.

d. Blend the oil or fat with the flour and ½ the sugar. Add the milk. Beat the whole egg, preferably in an electric mixer, adding ½ the sugar gradually. Add to cake batter.

Which method of mixing gives the best cake? Is one method of adding the flour preferable to another? Which method of adding the flour is quickest and easiest? Should cakes made with different fats always be combined by the conventional method, or can different methods be used to advantage for some fats and oils? Is there any advantage in separating the yolk and white of the egg in a plain cake?

F. To determine the effect of varying the proportion of the ingredients in the plain cake recipe upon texture, volume, and flavor.

Prepare the full recipe unless otherwise indicated. Cream by the method decided upon by the class. Follow directions under A. Use a tartrate baking powder, and divide the batter into 6 cakes of 150 grams each. Notice any changes occurring in the batter during mixing.

1. Increase the eggs in the recipe to 4. Prepare ½ the recipe, using a total of 100, 150, and 200 strokes, respectively, for the 3 cakes.

2. Repeat F1, but separate the yolk and white of the egg. Add the beaten white with the flour and milk.

3. Increase the sugar in the recipe to 1½ cups.

4. Increase the sugar in the recipe to 2 cups. Stir the left-over batter from the sixth cake a total of 1500 strokes, and bake 150 grams for a seventh cake.

5. Increase the fat in the recipe to ¾ cup. Prepare ½ the recipe, using a total of 100, 150, and 200 strokes for the 3 cakes.

6. Increase the sugar in the recipe to 1½ cups, the fat to ¾ cup, and the eggs to 3. A seventh cake may be baked from the batter left over after weighing the sixth cake. It should be stirred 1500 strokes.

7. Increase the flour in the recipe to 3½ cups. Prepare ½ the recipe, using a total of 100, 150, and 200 strokes for the 3 cakes.

Describe characteristic differences in the appearance of the crust for each series as the mixing is increased. The characteristic differences in crust when the proportion of different ingredients are changed. Compare the texture of each series. Of the different series. What is the effect on the volume of increasing the different ingredients? Which amount of mixing gives a cake of the best texture in each series? Do the cakes with the best texture usually have the best flavor? The increase of which ingredients increases tenderness, volume, velvetiness, toughness, and breadiness of the cake?

G. To determine the effect on the texture, volume, and flavor of plain cake of varying the ingredients used.

Prepare ⅙ of the recipe. Use the proportion of ingredients found best under F and the type of baking powder desired. Combine by whatever method the class decides to use, and mix with the number of strokes that will give the best texture for the brand of baking powder. Use 150 grams of batter for each cake.

1. Liquid.

Use: (*a*) milk; (*b*) water; (*c*) orange juice; (*d*) pineapple juice; (*e*) sour cream; and (*f*) sour milk. What other changes will need to be made for (*e*) and (*f*)?

2. Sugar.

Use different kinds of granulated sugar obtainable, such as (*a*) fine granulated, berry, and transformed; (*b*) powdered sugar; and (*c*) brown sugar. Always substitute sugar by weight.

3. Fat.

Double the salt for all fats other than butter. Use: (*a*) butter; (*b*) different types of lard, *e.g.*, grainy and smooth, and prime-steam and open-kettle rendered; (*c*) oil; (*d*) a hydrogenated fat; (*e*) butter plus 3% of its weight of commercial monoglycerides.

4. Flour.

Use: (*a*) a hard-wheat all-purpose flour; (*b*) a soft-wheat all-purpose; and (*c*) a specially prepared cake flour.

5. Dried egg.

a. Use 24 grams dried whole egg. Sift the egg with the flour. Increase the liquid by 72 grams. *b.* Reconstitute egg by adding the liquid gradually, then combine with creamed fat and sugar. *c.* Add reconstituted egg to the milk.

Chocolate Cake

Experiment 58.

A. To determine the amount and best method of mixing to give the best texture for a rich chocolate cake.

Recipe: *

Fat	1 cup	224 grams	Baking powder	16 grams
Sugar	2¼ cups	450 grams	Vanilla	1 teaspoon
Eggs	4	192 grams	Salt	4 grams
Chocolate	4 squares	113 grams		
Cake flour	3 cups	300 grams		
Milk	1 cup	244 grams		

Sift the flour and baking powder together twice for all the following experiments.

1. Mix by any of the methods given below, but it will be necessary to add all the flour and milk at one time. The full recipe will make 10 cakes of 150 grams each, so that portions of the batter may be removed after stirring 50, 100, 150, 200, 250, 300, 350, 400, 500, and 1000 strokes. For high altitudes the proportion of fat, sugar, and baking powder may need to be reduced.

2. Conventional method. Prepare ¼ of the recipe. Cream the fat, flavoring, salt, and sugar until very light and spongy. Add the beaten egg, and mix until very fluffy. Melt the chocolate carefully over warm water. Do not let it get too hot, as it should not melt the fat. Add to the fat mixture and stir thoroughly. For adding the flour and milk follow directions under Experiment 57D, method *a, b,* or *c,* but mix a total of 350 strokes or the number found best under 58, 1. For a loaf cake a pan with a top 8 by 4, bottom 7¼ by 3¼, and a depth 2¾ inches, of 5 cups' capacity, will be needed for ¼ of the recipe. For a layer cake a pan 7 by 7 and 2⅛ inches deep will be satisfactory. Bake at 195–200°C (about 385–400°F).

3. Use the conventional sponge method. See Experiment 57E, 6.

B. Temperature of baking.

Prepare the full recipe, using the method of mixing decided upon, adding the flour and liquid by method *a, b,* or *c,* Experiment 57D. Divide into 6 cakes of 235 grams each. Bake 1 cake at 165°C, 1 at 175°C, 1 at 185°C, 1 at 195°C, 1 at 205°C, and 1 at 215°C.

C. To determine the effect of varying the ingredients upon the color of the cake.

1. Use different brands of chocolate.
2. Use ½ teaspoon of soda, and reduce the baking powder to 3 teaspoons.
3. Use thick sour milk. Add ½ teaspoon of soda; reduce the baking powder to 3 teaspoons and the flour to 286 grams for the full recipe.

* This recipe was developed by Betty Ingersol Aitken.

4. Use brown sugar.

5. Mix enough of the following for ½ the recipe: butter, sugar, egg, chocolate, flavoring, and salt. After they are thoroughly mixed, weigh and divide into three parts. Use for *a, b,* and *c.*

a. In part 1 use a tartrate baking powder. The quantity of flour, baking powder, and milk will be for ⅙ of the recipe. Add flour and milk by method found best under A.

b. In part 2 use a phosphate baking powder.

c. In part 3 use S.-P. baking powder.

D. Substituting cocoa for chocolate.

Substitute 63 grams of cocoa for the chocolate. Also use larger and smaller quantities to determine the optimum quantity.

E. Use different types of fat.

Compare the appearance, shape of top, volume, and texture of the cakes made by the different methods. Is there any difference in tenderness? Is the texture of a rich chocolate cake better if the fat and sugar are thoroughly creamed? Which method requires the shortest time for mixing? Did the ingredients of your cake have a high or a low temperature while mixing? Is the flavor improved by adding soda? Do different brands of chocolate produce the same color? The same flavor? What is the effect of different types of baking powder on the color of the cake?

Devil's Food

Experiment 59.

To prepare devil's food.

Recipe:

Fat	½ cup	100 grams
Sugar	1⅓ cups	267 grams
Eggs	2	96 grams
Chocolate	3 squares	84 grams
Cake flour	2 cups	200 grams
Milk	1 cup	244 grams
Soda	1 teaspoon	4 grams
Salt	¾ teaspoon	3 grams

Cream the first 3 ingredients and the salt by method decided upon. Add the melted chocolate, and blend well. Sift the soda with the flour 2 times. Add the milk and flour by method *a, b,* or *c,* Experiment 57D.

A. The proportion of soda to give the best flavor.

1. Prepare ¼ of the above recipe.

2. Repeat 1, but reduce the soda to ¾ teaspoon for the full recipe.

3. Repeat 1, but increase the soda to 1¼ teaspoons for the full recipe.

B. To determine the effect of different brands of chocolate.

Try as many different brands of chocolate as you can secure.

C. To determine the effect of varying ingredients upon color of cake.

1. Substitute sweet milk for the sour. How much soda should be used? How much baking powder?

2. Use brown sugar.

With which proportion of soda is the real chocolate flavor retained best? Is the color the same with the different proportions of soda? What must the reaction be to give a deep red color to chocolate cake? With what reaction is the best flavor obtained?

White Cake

Experiment 60.

To determine the effect of mixing by different methods on the volume, texture, and tenderness of white cake.

Recipe:

Fat	¾ cup	168 grams	Flavoring	1 teaspoon
Sugar	2 cups	400 grams	Baking powder	3 teaspoons
Cake flour	3 cups	300 grams	Salt	½ teaspoon
Milk	1 cup	244 grams		
Egg whites	6	180 grams		

1. Conventional method. Prepare ⅙ of the recipe. The amount of mixing to give the best texture varies with the kind of flour used and may need to be determined. Cream fat and sugar. Add the salt and the flavoring. Sift the baking powder and the flour together several times. Add approximately ⅓ of the flour and ⅓ of the milk. Stir 100 strokes. Add a second portion of flour and milk, stirring a total of 200 strokes. Add the remainder of the flour and milk, stirring a total of 350 strokes. The egg whites are beaten until they flow slowly when the bowl is partially inverted. They are then added to the cake mixture and folded in with 50 folds, using a spatula. Weigh 200 grams of batter into a pan of 2½ cups' capacity. Bake at 185°C (365°F).

2. Repeat 1, but reserve ½ cup of the sugar. Add this sugar to the egg white gradually during beating. When the meringue stands up in peaks, fold into the batter.

3. Partially cream the fat and part of the sugar. Add the rest of the sugar and unbeaten egg white. Beat until light and creamy. Add the salt, flavoring, flour, and milk according to directions given under 1.

4. Thoroughly cream the fat, sugar, salt, and flavoring. Sift the flour and baking powder together several times. Add approximately ⅓ of the flour, ⅓ of the milk, and ⅓ of the beaten egg white. Stir 100 strokes. Add another ⅓ of the flour, milk, and the beaten egg white. Stir a total of 200 strokes. Add the remainder of the flour, milk, and egg white. Stir a total of 400 strokes.

Compare the appearance of the crust, the volume, the texture, the tenderness, and the flavor of the cakes. Which method gives the greatest volume? The most tender cake? What is the effect of folding the egg white too long? Which method is the easiest to prepare?

5. Variations.

a. Vary the proportion of ingredients, and determine the amount of mixing required to give the best texture.

b. Add all the flour and milk at one time instead of in several portions.

c. Add the flour and milk in several portions, but alternately.

d. Test the creaming ability of different fats, and determine how much the baking powder can be reduced when creaming is very thorough.

e. Determine the optimum baking temperature.

Gingerbread

Experiment 61.

To determine the effect of using baking powder or soda and sour milk for leavening in gingerbread.

Recipe:

Molasses	1 cup	328 grams
Sour milk	½ cup	122 grams
Fat	¼ cup	50 grams
Egg	1	48 grams
Flour	2 cups	224 grams
Ginger	1½ teaspoons	
Salt	½ teaspoon	2 grams

Optional

Cloves	½ teaspoon	Cinnamon	1 teaspoon
Allspice	1 teaspoon	Mace	½ teaspoon

A. Prepare ¼ of the recipe. Use 100 strokes for combining each cake unless otherwise stated. Weigh 180 grams of batter for each cake. Bake at 185°C (365°F).

1. Use 2 teaspoons of soda.
2. Repeat 1, but use 200 strokes in combining.
3. Repeat 1, but let stand 15 to 20 minutes before baking.
4. Use ¾ teaspoon of soda.
5. Use ¾ teaspoon of soda plus 1 teaspoon of baking powder.
6. Use 3 teaspoons of baking powder.
7. Use 3 teaspoons of baking powder, and substitute sweet milk for the sour milk.

B. Repeat A, substituting sorghum for the molasses.

What is the effect of soda upon the color of gingerbread? Does the baking powder affect the color? What is the effect of soda upon the gluten and the resulting texture of the gingerbread in 3 when the batter stands before baking? Why does it show more decidedly in the center and not so much at the edge of the cake? Would less mixing produce a better gingerbread?

CHAPTER 14

Fats and Oils

The principal uses of fats and oils in cookery are: (*a*) to give richness and flavor, as the addition of fat to vegetables, mayonnaise, and French dressing; (*b*) to fry or cook foods; (*c*) for shortening, as in biscuits, muffins, cakes, and pastries. For the first use, flavor is important and may be the deciding factor, unless cost needs to be considered. Examples are butter or bacon fat for vegetables in preference to lard or a hydrogenated fat, and olive oil for salad dressings in preference to other oils. For frying and shortening the chemical and physical characteristics of the fat are important. Of the simple lipides, only the fats (esters of fatty acids and glycerol) are considered herein. The esters of fatty acids and glycerol are known as glycerides.

Glycerides. In a simple triglyceride the three fatty acids combined with the glycerides are the same; in a mixed glyceride more than one kind of fatty acid is present. The two terminally linked fatty acids are known as α-, the center one as β-. If the two α-acids are the same the molecule is symmetrical; if different it is unsymmetrical. Although the simple glycerides, such as tristearin, are theoretically possible, they are seldom found in natural fats. The percentage of unsaturated fatty acids is of interest in products like pastry, for the shortening ability of the fat is related to this factor. The approximate percentage of unsaturated glycerides is: coconut oil, 6–8 (50); butter, 40 (50); lard, 60–65 (50); chicken fat, 77 (39); cottonseed oil, 75 (35); peanut oil from Spanish-type peanuts, 75 (36), from Virginia-type peanuts, 79; and corn oil 85 (37). Since the foregoing figures are approximate, it follows that individual samples of each oil or fat vary slightly, some having a higher and some a lower quantity of unsaturated fatty acids. In addition the fatty acid content of the fat varies with the location in the body and with the feed that the animal has received. Lard made from outer back fat is softer, *i.e.,* has less saturated fatty acids, more unsaturated ones, than lard made from leaf or perinephric fat (that around the kidney). In turn the outer back fat is softer than the inner back fat. Hilditch (31) gives the component fatty acids of the whole fat (in molar percentages) as tabulated.

	MYRISTIC %	PALMITIC %	STEARIC %	OLEIC %	LINOLIC %	C_{20-22} UNSAT. %
Outer back (sow)	3.8	20.3	7.9	54.1	13.0	0.9
Inner " "	3.8	26.0	11.0	44.1	13.6	1.5
Perinephric "	3.9	27.7	17.6	35.7	13.7	1.4

Peanuts or soybeans fed to hogs produce soft fat. At the Iowa Station (52) the iodine value of lard from lots of hogs on control and various soybean and soybean products diets varied from 63.6 to 83.4. Not only is the lard from pigs fed certain feeds soft, but also the fat of the meat and bacon is soft and oily.

Hilditch (31) found considerable fluctuation in the fatty acid content of milk fat with variation in feed. In general, milk fat from cows on winter feed had less unsaturated and more saturated acids than milk fat from cows on summer pasture.

Cruickshank (14) found the extent of unsaturation of fat of chicken is influenced readily by the fat in the feed. Although the iodine number of the fat may vary with individual birds, the fat throughout the body of a given bird has the same degree of unsaturation.

The pure glycerides (19), except those containing shorter chain acids than caprylic, are devoid of odor and taste. Refined oils and fats may be practically free of odor. Dean (19) states that only a few fats such as linseed, tung, and fish oils have a sufficiently characteristic odor to be recognized in mixtures of oils and fats.

Fatty acids commonly found in food fats. Hilditch (31) lists more than 40 "chief acids found as major and minor components, in natural fats," and adds that the list is not complete. A major component acid is defined as one composing from 10% upwards of the total fatty acids combined in a fat. A minor component acid would be less than 10% of the total. Some fatty acids are found only in traces; some are found in very large quantity in only one source. Most natural fats (19, 31, 48) contain 5, 6, or 7 acids present in major and minor proportions, whereas milk fat and fish oils may contain 12 to 15 such fatty acids. Some fatty acids, such as lauric (forming a large proportion of the fat of the laurel kernel) and myristic (sometimes forming as high as 75% of the Myristicacea, nutmeg family) have been given popular names that designate their source as a major component. When one saturated acid (31) is present in fairly large amount, subsidiary portions of the natural saturated acids next higher and lower in the homologous series are often observed also.

Saturated acids. The saturated acids have the general formula $C_nH_{2n}O_2$ or $C_nH_{2n+1}COOH$. Isovaleric acid (31) is one exception to the general rule that natural fatty acids contain an even number of carbon atoms and an unbranched chain in the molecule. It is found in large quantity in certain body fats of the porpoise. Lately a C_{17} branched-chain saturated acid has been reported in beef fat (27) and a C_{20} multi-branched chain in butterfat (26). Butyric, caproic, caprylic, and capric (19, 31, 48) are found in milk fat. The last three occur also in coconut oil. Lauric acid occurs in seed fats and milk fat. Of the saturated acids, Hilditch (31) states that palmitic acid may be considered the characteristic acid of the group. It may constitute 15–50% of the total fatty acids, and is completely absent from few, if any, of the natural fats. Of the other saturated acids (31) only myristic and stearic approach palmitic in "ubiquity of distribution." Stearic acid is abundant in ox and sheep depot fats. The saturated fatty acids are tabulated.

COMMON NAME	SYSTEMATIC NAME	STRUCTURAL FORMULA
Butyric	*n*-Tetranoic	$CH_3\cdot(CH_2)_2\cdot COOH$
Isovaleric	4-methylbutan-l-oic	$(CH_3)_2\cdot CH\cdot CH_2\cdot COOH$
Caproic	*n*-Hexanoic	$CH_3\cdot(CH_2)_4\cdot COOH$
Caprylic	*n*-Octanoic	$CH_3\cdot(CH_2)_6\cdot COOH$
Capric	*n*-Decanoic	$CH_3\cdot(CH_2)_8\cdot COOH$
Lauric	*n*-Dodecanoic	$CH_3\cdot(CH_2)_{10}\cdot COOH$
Myristic	*n*-Tetradecanoic	$CH_3\cdot(CH_2)_{12}\cdot COOH$
Palmitic	*n*-Hexadecanoic	$CH_3\cdot(CH_2)_{14}\cdot COOH$
Stearic	*n*-Octadecanoic	$CH_3\cdot(CH_2)_{16}\cdot COOH$
Arachidic	*n*-Eicosanoic	$CH_3\cdot(CH_2)_{18}\cdot COOH$
Behenic	*n*-Docosanoic	$CH_3\cdot(CH_2)_{20}\cdot COOH$
Lignoceric	*n*-Tetracosanoic	$CH_3\cdot(CH_2)_{22}\cdot COOH$
"Cerotic"	*n*-Hexacosanoic	$CH_3\cdot(CH_2)_{24}\cdot COOH$

Unsaturated acids. In the $C_nH_{2n-1}COOH$ series, acids containing 10 to 26 carbons are known. However, of these monoethenoid acids, oleic, according to Hilditch (31), is undoubtedly the most widespread of all naturally occurring fatty acids. Up to the present it has been found in all natural fats or phosphatides. It seldom forms less than 10 and may compose more than 50% of the total fatty acids of fats and oils. The tabulated formulas (31) are some of the common unsaturated fatty acids.

COMMON NAME	SYSTEMATIC NAME	STRUCTURAL FORMULA
Oleic	$\Delta^{9:10}$-Octadecenoic	$CH_3\cdot(CH_2)_7\cdot CH{:}CH\cdot(CH_2)_7\cdot COOH$
Linolic	$\Delta^{9:10,12:13}$-Octadecadienoic	$CH_3\cdot(CH_2)_4\cdot CH{:}CH\cdot CH_2\cdot CH{:}CH\cdot(CH_2)_7\cdot COOH$
Linolenic	$\Delta^{9:10,12:13,15:16}$-Octadecatrienoic	$CH_3\cdot CH_2\cdot CH{:}CH\cdot CH_2\cdot CH{:}CH\cdot CH_2\cdot CH{:}CH\cdot(CH_2)_7\cdot COOH$

The unsaturated fatty acids, linolic (a diethenoid acid, $C_nH_{2n-3}COOH$) and linolenic acid (a triethenoid acid, $C_nH_{2n-5}COOH$) are nearly as widespread as oleic, but occur in smaller quantity than oleic, except in the "semidrying" or "drying" oils of which they compose the major portion of the total fatty acids.

Characteristics of Fats and Oils

One distinction between fats and oils is that at ordinary temperatures, 18–24°C, the fats are solid and the oils are liquid. Chemically the fats contain higher percentages of the saturated glycerides than the oils, and the oils contain more of the unsaturated glycerides than the fats.

Fats and oils are only sparingly soluble in alcohol but are readily soluble in ether, chloroform, and carbon tetrachloride. Fats and oils are insoluble in water. They have a greasy feel and produce characteristic transparent spots on paper.

The fats, the fatty acids, and the soaps formed from the fatty acids and alkalies all lower the surface tension of water.

Specific gravity of fats and oils. All the naturally occurring fats and oils have a specific gravity of less than 1.0. The average specific gravity of some edible fats and oils is tabulated.

Butter	not less than 0.905 at 40°/40°C
Cottonseed oil	about 0.917–0.918 at 25°/25°
Corn oil	about 0.919–0.921 at 25°/25°
Lard	about 0.931–0.932 at 15°/15°
Olive oil	about 0.916–0.918

Melting point of fats. Because fats are composed of a mixture of glycerides their melting points are not constant but vary. The melting point of fats is affected by (*a*) the percentage of component unsaturated fatty acids and (*b*) the length of the saturated acid chains. In general, fats containing a higher percentage of component unsaturated fatty acids, like the oils, have low melting points; those with a high percentage of short-chain saturated acids, like coconut oil, have intermediate melting points; and those with a high percentage of long-chain saturated fatty acids, like mutton tallow, have high melting points. Butter produced in summer has a lower melting point than butter produced in the winter because the percentage of unsaturated fatty acids is higher in the summer.

Congealing point. The solidifying point of a glyceride or a mixture of glycerides is lower than the melting point, the difference in the two often being great. For example, Bloor (6) cites the melting point of a sample of tristearin as 71.5°C, whereas the solidifying point was 52.5°C. A sample of butter melted at 34.5° but congealed at 22.7°C. This wide spread in melting and congealing points has some advantages and some disadvantages. When melted fats are added to a batter or other product they do not solidify as rapidly as they would if the melting and congealing points were the same. On the other hand, butter once melted requires a lower temperature to congeal.

Titer is the temperature at which fatty acids obtained by alkaline hydrolysis of fat resolidify.

Iodine value. The iodine number or value is the number of grams of iodine absorbed by 100 grams of fat or other substance. The iodine is absorbed at the unsaturated carbons. Jamieson (34) states that the iodine number of an oil indicates the class to which it belongs. The non-drying oils have iodine values below 100; they include avocado, almond, cocoa butter, castor, olive, palm, coconut, and peanut. The semidrying oils have iodine values between 100 and 130; they include corn, cottonseed, sesame, wheat, oat, rice, rye, Brazil nut, raisin seed, kernels of peach, cherry, apricot, and many others. The drying oils, which include linseed and soybean, have iodine values above 130. The fats used in food products have iodine values below 100.

Acid value. Acid value is defined as the number of milligrams of KOH required to neutralize the free fatty acids in 1 gram of substance. It is a measure of the quantity of free fatty acids or those not combined in glycerides, and it is usually reported as "free fatty acids as oleic."

Refractive index. The refractive index is the degree of deflection caused in a ray of light in passing from one transparent medium to another. For some fats the iodine value may be calculated with a fair degree of accuracy from the refractive index. Since the determination can be made rapidly, the refractive index is used to determine the extent of hydrogenation during the hydrogenation process.

Peroxide value. The peroxide value is the amount of peroxide present per 1000 grams of fat. It is expressed as milliequivalents or as millimoles, 1 millimole equaling 2 milliequivalents. The peroxide is determined in accelerated tests to learn the relative induction periods or relative keeping quality of fats. King, Roschen, and Irwin (41) describe the principle of this test as follows: By aerating a sample of fat in a tube held at constant temperature in a bath, the aging of the fat is greatly accelerated. They state that the temperature at which the fat is held, the surface exposed, the amount of oxygen available, the amount of agitation, and the presence or absence of light, all have a bearing on the peroxide value. When these conditions are controlled, an accelerated test may be completed in a short time.

Hydrogenation. Hydrogenation is the process by which hydrogen is added to the unsaturated carbon bonds of oils, thus forming hard fats. When a metal catalyst, usually nickel, is used at an elevated temperature in the presence of hydrogen, the unsaturated bonds of oils and soft fats take up hydrogen. Depending upon the completeness of hydrogenation and whether some oil or soft fat is mixed with the product, the resulting fat may have varying degrees of hardness and plasticity. By controlling the amount of the catalyst, hydrogen pressure, and other factors, some selectivity in hydrogenation of the unsaturated bonds is brought about. For some types of shortening it is desirable to leave most of the oleic acid unhydrogenated and hydrogenate the 15–16 carbon double bonds of linolenic acid and the 12–13 carbon double bonds of both linolenic and linolic acids. The hydrogenated vegetable oil shortenings commonly used throughout the United States are not completely hydrogenated. They contain about 25% of the saturated fatty acids. If they were completely hydrogenated the product would be too hard to use in food preparation. In addition to oils or mixtures of oils some soft lards are also hydrogenated for edible purposes.

A completely hydrogenated fat is very hard and brittle like china. It can be ground and mixed with oil or fat as discussed in the chapter on bread.

Texture and consistency of fats. The texture or consistency of a fat, and hence its properties in baked products, is influenced not only by its component glycerides, but also by the rate of cooling and mechanical agitation. For example, if a sample of lard is divided into two parts, and one portion is cooled slowly, *i.e.,* kept in a warm room or an incubator just below the congealing point of the fat, the glycerides with high melting points tend to crystallize and separate from those with low melting points. As a result the crystallized glycerides form granular spots surrounded by oil. If the second portion of lard is chilled rapidly, there are fewer granules and the fat is not so grainy. If, in addition to rapid chilling, the fat is also stirred while it is being cooled it becomes very smooth. If the temperature to which it is cooled is several degrees below its melting point the fat may become waxy and so firm that it is rather difficult to cream at ordinary temperatures. The oil does not separate from the smooth fat as the fat becomes soft. It is for this reason that only smooth lard or fat is sold in paper cartons. The commercial smooth lards are not cooled sufficiently to become waxy.

Glycerol. When fats are acted upon by lipase enzymes or are hydrolyzed by alkalies, *i.e.,* saponified, glycerol or glycerin and fatty acids are formed. Glycerol is decomposed by heat, losing two molecules of water and forming acrolein. Acrolein is an aldehyde that has a sharp odor and is irritating to mucous membranes of the nose and throat and to the eyes. The odor and irritation are familiar to all who have had experience with "burning fats."

Free fatty acids. Some free and uncombined fatty acids and glycerol are usually found in fats and oils. The amount of free fatty acids is greater in some fats and oils than in others. Fats are hydrolyzed (*a*) by lipases, (*b*) by boiling with alkalies, and (*c*) to a lesser extent during heating in the presence of moisture, into fatty acids and glycerol. Foods with a high water content (53), like potato, when cooked in fat, increase the free fatty acid content more than food with a smaller water content, like doughnuts.

The smoking temperature of fats. When fats or oils are heated to a high temperature decomposition occurs and finally a point is reached at which visible fumes are given off. This is the smoke point. Some fats decompose at lower temperatures than others; those that smoke at low temperatures are not pleasant to use because of the odor and irritating effect of the fumes. The decomposition products also give an unpleasant and disagreeable flavor to the food. Hence it is preferable to use fats with high smoking temperatures for frying.

Blunt and Feeney (7) investigated the smoking temperatures of edible fats. They found the smoking temperatures of various fats when tested in small evaporating dishes having a diameter of 3.75 inches and in large kettles. The former are given in Table 38.

TABLE 38

The Smoking Temperatures of Some Edible Fats (*Blunt and Feeney*)

Kind of fat	Smoking temperature, °C	Free acid as oleic, %
Cottonseed oil (Wesson)	233	0.07
Snowdrift	232	0.06
Crisco	231	0.13
Leaf lard	221	0.15
Butter fat	208	0.28
Leaf lard heated 5 hours	207	0.34
Bulk lard	194	0.51
A much-used lard	190	0.61
Olive oil	175	0.92
Peanut oil, I	162	1.10
Peanut oil, II	149	1.64
Coconut oil	138	1.90

The following factors cause variations (7) in the smoking temperatures of fats and oils: (*a*) the amount of free fatty acids present, (*b*) the surface exposed, and (*c*) the presence of foreign particles.

Free fatty acids. The fats with the highest percentage of free fatty acids, Table 38, had the lowest smoking points. To confirm that the smoking point of a fat is closely related to its free acid content, Blunt and Feeney (7) removed the free fatty acids from some of the olive oil and found its smoking point to be 234°C, its free acid, as oleic, 0.03%. To some of the cottonseed oil, oleic acid in different proportions was added, its smoking temperature being lowered with the increased oleic acid content.

Surface exposed. The smoking temperature (7) for a particular fat is lowered when the exposed surface area of the fat is increased. The wider the diameter of the cooking utensil, the more the smoking temperature is lowered. A vessel with as small a diameter as is convenient should be used for frying.

Foreign particles. The presence of finely divided foreign particles lowers the smoking point. Flour and small particles of other materials accumulate in a fat used for cooking purposes. Because of these flour particles the smoking point (53) is lowered to a greater extent after frying doughnuts than after frying potato chips, even though the free fatty acid content of the fat in which the chips are fried is the higher.

The smoking temperature affects the fat absorption. (Fat absorption (52) is greater in the fats with the lowest smoking points.)

Shortenings

Kester (40) describes the minor oil-producing crops of the United States, but most of the edible fats come from butter, lard, soybean oil, cottonseed oil, peanut oil, and corn oil or are processed from some of these products. To the homemaker any fat that increases the tenderness of a product is a shortening. In the fat and oil trade, the term shortening specifies a hydrogenated product, although the definition of various types of shortenings varies somewhat with the source. Shearon et al. (70) give four types of shortenings as follows: (*a*) standard shortening consists of a mixture of 60-titer stearin, oil partially hydrogenated to a definite end point, and a soft fat or unhydrogenated oil. This mixture gives a fat that is easy to handle over a wide temperature range; (*b*) hydrogenated fat consisting entirely of hydrogenated oil, all the fat in the product having been through the hydrogenation process; (*c*) the emulsifier type of shortening has superglycerinated fat added (superglycerinated fat has a high proportion of monoglyceride); and (*d*) B & C, biscuit and cracker (products needing long shelf life) hydrogenated to remove all the linolenic and linolic fatty acids. Shortenings may be all animal, all vegetable, or a mixture of animal and vegetable fats.

According to reports in the literature, the character of lard as a shortening may be changed by interesterification or molecular rearrangement so that it resembles the hydrogenated vegetable shortenings.

Rancidity

Prevention of rancidity is an important problem in many foods. Some of these foods are crackers, cookies, and fruit cake; cereal products, including breakfast cereals; confectionery products; dairy products—butter, ice cream, cheese, and dry milks; dry whole eggs and yolks; infant foods; fats and oils, including medicinal preparations of fish liver oils; nuts of all kinds; potato chips; salad dressings; meat, particularly cured meats, bacon, ham, and fish; frozen meats, poultry, and fish; frozen made dishes; dried vegetables and even in some frozen vegetables. Although the fat content of most vegetables is very low, it may be the major source of off flavors in dried and frozen vegetables.

The term rancidity is used by the housewife to designate the development of any disagreeable odor and flavor in fats and oils. The term is applied differently in the fat industry and the dairy industry to spoilage or deterioration brought about in a particular manner. At present it is being used often in its widest sense to include all flavors and odors in fats and oils, but the manner in which rancidity is produced is specified.

Rancidification is detected organoleptically as readily as by chemical and physical tests, for no tests have been devised that are sensitive enough to follow the development of rancidity in its early stages. In addition all standards used for the detection of rancidity are ultimately based on taste and smell. Hence scientific investigation of rancidity is rendered difficult.

Types of fat spoilage. Lea (48) lists four causes for rancidity of fats: (*a*) absorption of odors, (*b*) action of enzymes present in the tissues, (*c*) action of microorganisms, and (*d*) atmospheric oxidation. The first three (48) are designated as the lesser causes of rancidity.

Holm (32) states that the lipids of milk are involved in more spoilage than any other milk constituent. He lists these types: (*a*) rancidity, caused by hydrolysis of the glycerides; (*b*) tallowiness, caused by the oxidation of unsaturated fatty acids; (*c*) "oxidized" flavors, generally ascribed to the oxidation of phospholipids; and (*d*) "fishiness," ascribed to both oxidative and hydrolytic processes.

Fat and oil chemists define rancidity as oxidation of unsaturated fatty acids with the resultant secondary products. They also add flavor reversion to the list. This results from combination of less oxygen with the fat than in ordinary rancidity.

Absorption of odors includes taints from packing and packaging materials, paints, or other products or foods stored in the vicinity of the fat or fatty food. Fats, egg yolks, fat of milk, and fat of meats are all likely to absorb foreign odors, many of which may remain in the food after cooking.

Hydrolytic rancidity is brought about by lipase enzymes in the tissues. The enzymes are held in check in the living organism. The action of lipase is retarded by low temperature. Thus fishes (48), since their body temperature is never more than a few degrees higher than their environment, require for their metabolic processes powerful enzymes which retain an unusual degree of activity at low temperatures. The hydrolytic products are fatty acids and glycerol. The flavors developed by lipase action depend upon the composition of the fat. Thus flavors caused by butyric acid will be found chiefly in products containing butter or cheese since few of the common food fats except milk fat contain butyric acid. Davies (17) states that butyric and capric acids are detectable by smell and taste in concentrations of less than 80 ppm. Except for secondary reactions, lipase activity (17) is of greatest economic importance in fats containing high percentages of the lower fatty acids. Free fatty acids may act as catalysts for oxidative changes. Since lipase enzymes are destroyed by heat, this type of rancidity is encountered in products not heated to a high enough temperature to destroy the enzymes.

Soaps and glycerol are formed when fat is saponified. Usually this occurs at high temperatures. However, over a long period of time, as in mixes, some fats such as coconut will react with $NaHCO_3$ to form soap at low temperatures. A soapy flavor in foods of high fat content is usually attributed to the formation of ammonium soaps, the NH_3 for the reaction being derived from the protein.

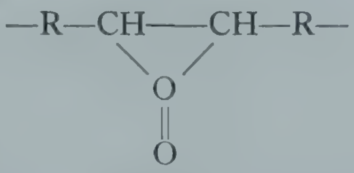
Microorganisms do not grow in a pure fat. But many foods of high fat content also contain moisture and non-fatty tissues. In these, rancid products may be produced.

Fishiness, according to Davies (17), is caused by the production of trimethylamine in the presence of catalysts from lecithin. It occurs most commonly in butter. The presence or absence of other products may alter the fishy odor.

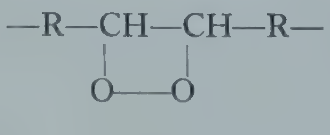
Oxidative rancidity. The autoxidation of fats and oils, *i.e.,* the spontaneous taking up of oxygen by unsaturated fats exposed to the air, is known as oxidative rancidity. From several standpoints it is the most important of the methods by which rancidity is produced. The rate at which oxidation occurs varies with the fat and the conditions of storage. Coe (12) states that the factors known to accelerate oxidation are numerous, but the most important ones affecting the market life of a fat are: (*a*) the primary factors, *i.e.,* metals and light; and (*b*), the contributory factors, air, temperature, moisture, and photosensitizers. To these may be added the surface area of the food exposed to the air.

Induction period. The period before the uptake of oxygen becomes appreciable is known as the induction period. Mattill (57) states that the changes during the induction period are less obvious than those following this period. Once (57) the "induction period is past, events seem to follow thick and fast in greatest confusion, but like the devastating speed and apparent disorder of a blitzkrieg, everything nevertheless goes according to plan. The plan is flexible and is in part dictated by the events themselves. Further careful study is needed to indicate what the events are and why they take place." The induction period arbitrarily ends with the organoleptic detection of rancidity. The length of the induction period varies for different fats and oils and for different samples of the same fat or oil. In addition, the end of the induction period is not sharply defined for all fats. The products of oxidation are autocatalytic so that oxygen uptake is accelerated as rancidification progresses.

The mechanism of autoxidation. Various mechanisms have been proposed for the addition of oxygen to fats in the primary reaction of oxidative rancidity. Among these are the formation of a moloxide, a peroxide, and hydroperoxide, with subsequent reactions (5, 15, 72), as illustrated.

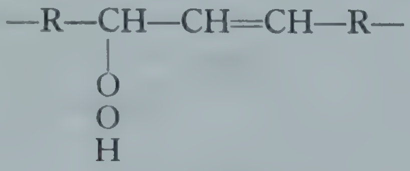


Moloxide



$$\begin{array}{c}\mathrm{-R-CH-CH-R-}\\ \quad | \qquad\ \ | \\ \mathrm{O\!-\!\!-\!O}\end{array}$$

Peroxide



$$\mathrm{-R-\underset{\underset{\underset{\displaystyle H}{\displaystyle O}}{\displaystyle O}}{\underset{|}{CH}}-CH{=}CH-R-}$$

Hydroperoxide

The most favored mode of oxidation at this writing is the hydroperoxide. Many chemical changes occur in fats as the concentration of peroxides increases. There are decreases in fluorescence, interfacial tension, iodine value, linolic acid, the average chain length of the fatty acids, total unsaturation (22, 53) and increases in refractive index and peroxide value (22, 53). Lips (51) gives a longer list. The development of rancidity is often determined chemically by the peroxide value. The peroxides (51) vary in their rate of breakdown to the secondary reaction products. Thus the peroxide values of the same and different fats vary with the fat and the conditions of storage. Lips (51) states that in lard, in which oleic acid is the chief fatty acid, very little peroxide forms before the secondary breakdown occurs and a value of 20 milliequivalents of peroxide/kg roughly indicates rancidity. Corresponding values for hydrogenated lard, oleo oils, and hydrogenated vegetable fats are approximately 40, 60, and 80 milliequivalents, respectively. Other peroxide values that indicate that rancidity can be detected organoleptically for these and similar compounds have been reported.

There is considerable work at present to identify the secondary products, the volatile carbonyl compounds. See references by Swift et al. (72), Pool and Klose (67), and Kawahara et al. (38).

Metals. Traces of certain metals (48) may act as catalysts, copper in particular being an active pro-oxidant; lead, iron, and zinc are intermediate, whereas tin and aluminum are the least active of the metals studied. Two parts of copper per million are sufficient to produce incipient rancidity in butter after storage for 6 days at room temperature. King, Roschen, and Irwin (42) find that copper in any form is an active pro-oxidant; the other metals are arranged in varying order, depending upon whether they are in solution in the fat or in sheet metal. Dissolved iron is active, the solid form inactive; dissolved tin is inactive, but sheet tin catalyzes oxidation.

Some fats contain an aqueous phase with non-fatty materials. Lea (48) finds that metallic salts dissolved in this aqueous phase affect the rate of oxidation. Copper is twenty times more active than iron.

Light. Light accelerates the development of rancidity in fats. However, Coe and LeClerc (13) found that green light of 490–580 mμ wavelengths, or 4900–5800 angstrom units, inhibits development of rancidity, although oils or fats stored at low temperatures and with all light excluded remained fresh longer than if treated with antioxidant or packaged in green wrappers and exposed to light at room temperature. Ultra-violet light (48) accelerates the development of rancidity in fats very rapidly. Of the visible spectrum the shorter wavelengths of light, the blues below 4700 angstroms, are the most harmful in accelerating rancidity.

Nutritive value. Vitamin A in fats (28) is destroyed when fats become rancid through oxidation. In extreme rancidity (48) loss of vitamin D may also occur.

Moisture. The moisture content of a product may affect the rate of fat deterioration. Flour (23) keeps best at its normal moisture content of 10–12%; at 2% it becomes tallowy and rancid. Crackers (73) deteriorate more rapidly with 1% moisture than at their normal level of 5–6%. The low moisture content of cereals (21) to render them crisp is conducive to rancidity development. On the other hand, dried whole egg, egg yolk, and milk keep better with a low moisture content, 2% or less.

Surface area. Products like potato chips, salted nuts, and flaked cereals present a large surface area to the air, and it is not practical to package potato chips and flaked cereals in a vacuum. Elder (21) has reported that salt acts as a pro-oxidant in flaked cereals, whether the salt is cooked with the cereal or sprinkled on the surface after cooking. Salt also acts as a pro-oxidant in pork sausage during frozen storage of the sausage and in ham and bacon.

The stability test. This test (41) has been mentioned under peroxide value. It is now known as the active oxygen method (AOM). The deterioration of the fat at high temperatures of the test is as rapid in a few hours as in a few weeks or months when stored at lower temperatures with light and air excluded. Although the stability test is used to determine the keeping life of a fat, it does not always indicate the keeping quality of the fat or oil in a food product. It has been found (74) that the induction period of crackers is not related to the induction period of the isolated fat. A fat may show excellent keeping quality in the isolated form, but may deteriorate rapidly in certain mixtures, and *vice versa.* McKinney and Bailey (60) warn that the accelerated test cannot be relied upon to foretell the speed with which the fat becomes rancid in a food product.

Antioxidants. An inhibitor of autoxidation of a fat is known as an antioxidant; an accelerator, as a pro-oxidant. Fats and oils always contain at least traces of different substances in varying proportions, some of which may act as antioxidants. Mattill (58) states that with few exceptions the *ortho* and *para* di- and poly-phenolic compounds are the only substances that have primary antioxidant action on fatty acids. Other substances that delay autoxidation should be called synergists because they reinforce the effect of the polyphenolic compounds. By Mattill's definition, lecithin, the acids, citric, phosphoric, ascorbic, etc., are synergists. The polyphenols (49) act as chain breakers in the autoxidative process. Vegetable oils contain natural phenolic substances such as the tocopherols, vitamin E, and other phenolic compounds which are inhibitors. Animal fats are lacking in tocopherols.

The ingredients combined with fats in baked goods and other products may have anti- or pro-oxidative action. The protective or adverse action may vary under different conditions. Spices (11) exhibit antioxidant properties, those of rosemary and sage being pronounced. Sugar, lecithin, and cereal flours such as soybean, oat, corn, and unbleached wheat flour possess some antioxidant properties, but they are far from ideal antioxidants. The ideal antioxidant (44) can be used in low concentrations, added to the fat with ease, has carry-over, is readily available, reasonable in cost, contributes no objectionable flavor, odor, or color to the fat or foods in which the fat is used, and is physiologically harmless.

At present the Meat Inspection Division of the Bureau of Animal Husbandry allows the following antioxidants to be included in animal fats: resin guaiac; nordihydroguaiaretic acid (NDGA), alone or in combination with citric or phosphoric acid; tocopherols; lecithin; citric acid; propyl gallate (alone or in combination with citric acid); and butylated hydroxy anisole (BHA), alone or in combination with NDGA or propyl gallate, with or without citric acid or phosphoric acid. Most antioxidants offer more protection to lard than to cottonseed oil, but they can also be used in vegetable fats.

The effectiveness of the foregoing phenolic antioxidants is increased if a synergist is added. Moore et al. (61) used three concentrations of 13 antioxidants (12 of phenolic type) in 3 fats: lard, cottonseed oil, and hydrogenated cottonseed oil. No synergists were added. The effectiveness of the antioxidant varied somewhat with the concentration used and decidedly with the fat. More protection against rancidity was afforded lard than cottonseed oil products. Propyl gallate was the most effective antioxidant with the products used. Moore et al. did not test the carry-through of the antioxidant. By carry-through is meant protection of the baked or other product in which the fat is used.

The following tabulation indicates roughly the effectiveness of the antioxidants permitted in lards. The material was obtained from several sources (8, 44, 54, 61), and it is difficult to evaluate experiments done on different fats in different laboratories. The AMI-72 is the American Meat Institute formula used in many lards at the present time.

ANTIOXIDANT	ANTIOXIDANT PROPERTIES	CARRY-THROUGH
Tocopherols	Fair	
Gum guaiac	Poor	
Lecithin	Poor	
Propyl gallate	Good	Low
NDGA	Good	Low
BHA	Fair	Excellent
AMI-72 { BHA 0.020% Propyl gallate 0.003% Citric acid 0.002% }	Good	Good

Some antioxidants are not suitable for prepared bake mixes when the shelf life is comparatively long. The discolorations produced are given under mixes in Chapter 13.

Magoffin et al. (55) report that BHA added to either animal or vegetable fats as an antioxidant has had carry-through for potato chips. The tests were done on both a laboratory and a commercial scale. The addition of propyl gallate and citric acid enhanced the carry-through antioxidant properties.

Flavor reversion. Lips (51) defines flavor reversion as flavor deterioration originating with less oxidation than is required to produce oxidative rancidity. Any fat (16) may have a tendency to reversion, but the time is so long for some fats that it causes no practical problem. However, reversion is an important problem in shortenings made from oils containing high proportions of unsaturated fatty acids (3 double bonds per chain) as in soybean and linseed oils. Shortenings from cottonseed and peanut oils present no reversion problems. Although deodorized soybean oil shortenings are bland when fresh, as reversion occurs they become "beany," grassy, painty, metallic, and finally develop a fishy flavor (8, 16, 53). Daubert and O'Connell (16) report that if the proportion of soybean oil is below 25–35%, detectable reversion ordinarily does not occur in margarine and shortening. The initial quality of the soybean oil has an important effect on its stability when made into shortening. There is less reversion with some than with other oils.

Storage of fats. Triebold and Bailey (73) state that the most striking result of their study is the effect of air on the length of the induction period. All hydrogenated samples stored in unopened containers showed induction periods of approximately the same length. Samples from containers once opened and then restored had shorter induction periods. A lard sample stored in the laboratory for a year with air excluded appeared in as good condition at the end as at the start of the experiment. They emphasize the practical importance of preventing undue exposure of shortenings to air and decreasing the surface area of the fat exposed to air.

Changes in Fats during Cooking

Masters and Smith (56) state that the changes occurring in the fat in cooked pastry are slight, unless the pastry is very thin or overcooked. Chang et al. (10) used lard, the least stable of the plastic fats in biscuits, pastry, and gingersnaps. The fatty acid content of the baked products did not differ significantly from that of the fat in the dough.

Changes occur in the fat used for frying potato chips (43, 53) and doughnuts (7, 10, 25, 46, 53, 62, 64, 76) and in the fat extracted from the potato chips or doughnuts. Some of the changes that occur are: (*a*) an increase in free fatty acids, (*b*) an increase in the refractive index, (*c*) a decrease in the iodine number, (*d*) lowering of the smoke point, (*e*) lowering of the melting point, (*f*) increase in peroxide value, (*g*) polymerization of the fat, and (*h*) darkening in color of the fats. Heating the fat alone (62) for the same period as that used for cooking doughnuts did not bring about as great changes in the fat as were brought by heating with food in the fat. When doughnuts (52) were cooked at three temperatures, it was found that the changes in iodine value, smoke point, the free fatty acid content, and the peroxide value were more rapid at 200°C than at 185°C, and in turn more rapid at 185° than at 170°C.

In most studies in which the fat absorbed by the food (43, 76) has been compared with the fat in which the food has been cooked, it has been found that the fat extracted from the food underwent greater changes in chemical and physical constants than the fat in which the food was fried.

Potato chips contain more water than doughnuts. As the product is being cooked part of the moisture lost from the food bubbles through the fat in the form of steam. Porter et al. (68) emphasize that with more water in the fat the formation of free fatty acids is increased. The comparative changes (53) after cooking doughnuts and potato chips in different samples of the same fat follow: The iodine number of a given fat was lowered to a greater extent after frying potato chips than after frying doughnuts. The free fatty acid content, in general, was higher after frying potato chips. The smoking point was lowered more after frying doughnuts than after frying potato chips. In addition, if a fat smoked during its use, it smoked in a shorter time and more profusely when frying doughnuts than when frying potato chips. The fats discolored to a greater extent after frying doughnuts than after frying potato chips.

Polymerization of the fat molecules increases the viscosity of the fat and, if polymerization is great enough, gum may be formed. This gum (53) forms at the edge of the container and the fat line, the quantity being greater with oils than with fats. All fats darkened in color with use, the extent being greater in the fats that smoked early in the cooking procedure. A highly significant correlation was found between the iodine value and the refractive index (52). All investigators have found a high negative correlation between the smoking point and the free fatty acid content (7, 46, 53).

Goodman and Block (25) point out that in commercial frying of doughnuts the surface is cracked and the doughnuts misshaped until the free fatty acid content reaches a certain point. In their studies the free fatty acid content reached 0.74% through normal continuous frying with fresh fat added at regular intervals. Lantz and Carlin (46) found the percentage of free fatty acid varied with different fats. The maximum amount found by King et al. (43) was 0.88%. Porter et al. (68) found that an objectionable flavor of the doughnuts was noticeable when the free fatty acid content reached 2.0% or higher.

Chang et al. (10) found that during heating of a vegetable oil the changes in the oleic acid content were small, the linolic decreased, whereas the linolenic decreased at first, then increased until it was higher than in the original fat.

Doughnuts

McKee (59) made doughnuts under standardized conditions, frying them 5 minutes at 200°C. The standard recipe averaged 34.7% fat absorbed. When the fat was doubled and quadrupled in the doughnut recipe the fat absorption was increased to 43.4 and 47.8%, respectively; sugar doubled caused an increase to 44.3%. When the sugar was quadrupled the doughnuts disintegrated during cooking, absorbing large quantities of fat.

Morgan and Cozens (62) used lard, olive oil, and two hydrogenated cottonseed oil products to fry doughnuts. Their dough contained less egg and a larger proportion of flour than the dough used by McKee. In addition their doughnuts were larger, which gave relatively less surface area. They were cooked 3 minutes at 205–210°C. The average fat absorption was 17.4%. The fats absorbed in larger amount showed higher refractive indices and also larger increases in these numbers. The fats having the greatest amount of free fatty acids were absorbed to the greatest extent.

In the study at Iowa State College (53) the fats were heated for 10 hours and 14 minutes. This includes the preliminary heating, the cooking period, and heating after frying the last food, if necessary. No new fat was added during the cooking periods. The fats included open-kettle rendered, prime-steam rendered, and drip-rendered lards, hydrogenated lard, hydrogenated cottonseed oil, and corn oil. The results follow:

Fat absorption. (*a*) Fat absorption was less if the dough temperature was near 26°C, greater if near 24°C. (*b*) A significant negative correlation was found between fat absorption and smoking point of the fat, greater absorption occurring in doughnuts cooked in fats with the lower smoking point. (*c*) There were no significant differences in fat absorption for doughnuts cooked at three temperatures, 170°, 185°, and 200°C, the cooking time being the same at all three temperatures. (*d*) The longer the dough was handled and rerolled the less the fat absorption. "Firsts" (the 24 doughnuts cut from the first rolling of each mix) always absorbed more fat than "rerolls" (the 12 doughnuts obtained from scraps of dough after first rolling), and rerolls in turn absorbed more fat than the "re-rerolls" (the last six doughnuts from scraps left from rerolls). The percentage of fat absorbed in studies III and IV is tabulated.

Part	Firsts	Rerolls	Re-rerolls
III	27.5	21.4	18.0
IV	28.6	22.3	18.5

Palatability. In general, the first doughnuts cooked in a fat were more palatable than those cooked after the fat had been used for some time, although there were exceptions. If the fat had an odor at the start of cooking, the doughnuts were more palatable after this odor had volatilized. Doughnuts cooked at the lowest temperature ranked higher than those cooked at the highest temperature, particularly after the fat had been used. The results are given in Table 39.

TABLE 39

TOTAL SCORES FOR THE FIRST AND LAST LOT OF DOUGHNUTS COOKED IN THE FOUR FATS AT THE THREE TEMPERATURES INDICATED

	Frying temperature					
	170°C		185°C		200°C	
	First 6 fried	Last 6 fried	First 6 fried	Last 6 fried	First 6 fried	Last 6 fried
Drip-rendered lard	78.0	82.7	87.0	63.7	50.0	33.0
Open-kettle-rendered lard	61.7	62.7	68.0	44.3	52.3	26.7
Hydrogenated lard	85.0	81.3	69.7	62.0	51.7	41.7
Corn oil	80.3	65.0	73.7	49.3	57.7	30.7

Additional Factors Affecting the Amount of Fat Absorbed during Cooking and the Texture of the Doughnuts

Some of the factors affecting fat absorption in doughnuts have been considered. Others follow:

Surface area. Other things being equal, the greater the surface area the greater the fat absorption. The total surface area of doughnuts may be increased by stretching the dough in handling and by cracks on the surface of the dough. The cracks and the roughness of the surface of the rolled doughnut vary greatly with the technic of different operators. The thicker the doughnut is rolled, the smaller the total surface area in proportion to the weight of the doughnut. The thickness of the doughnuts can be controlled by rolling the dough between cleats tacked to a bread board.

Temperature of the ingredients when mixed. The results in Table 40 show that the temperature of the ingredients when mixed has a decided effect upon the amount of fat absorbed during cooking. The tenderness of the doughnuts was as marked as the fat absorption, for all doughnuts of series II were tougher than those of series I. The dough made from the materials that had been incubated at 40°C developed very rapidly, becoming quite elastic and rubbery in a short time. The dough stretched yet was so tenacious that it was difficult to divide it. It had a tendency to draw up and shrink after rolling. The best temperature of the ingredients to secure doughnuts of desirable texture and tenderness is about 25°C (77°F). The percentage of fat has been calculated on the cooked weight of the doughnuts. However, the uncooked weight is also given so that fat absorption may be calculated on the uncooked weight and the moisture loss during cooking may also be determined.

TABLE 40

VARIATION IN FAT ABSORPTION DUE TO DIFFERENCE IN TEMPERATURE OF THE INGREDIENTS OF THE DOUGH WHEN MIXED, SIX DOUGHNUTS IN EACH LOT. COOKED 3 MINUTES AT 175° TO 180°C

Experiment 63	Number strokes for mixing	Temperature of ingredients when first mixed	Weight of uncooked doughnuts, grams	Weight of cooked doughnuts, grams	Fat absorbed	
					Grams	%
I, 1	60	22°C	140.6	181.1	60.5	33.4
2	80		143.5	179.5	55.5	30.9
3	100		144.0	175.0	47.0	26.8
4	120		141.0	169.9	47.0	27.8
II, 1	60	40°C	146.6	158.6	28.0	17.6
2	80		145.8	154.8	26.0	16.7
3	100		153.7	161.7	24.5	15.1
4	120		150.4	159.4	24.5	15.3

The extent of mixing the dough. The effect of handling the dough on fat absorption has been considered, and the effect of extent of mixing is shown in Table 40. The method of mixing and the extent also affect the texture and tenderness of doughnuts. Doughnuts, like cakes, seem to have a finer, more even texture if the eggs are creamed thoroughly with the fat and sugar. Adding the flour and milk in different portions may also affect the texture. Too little mixing gives a coarse, harder texture, for the ingredients are not thoroughly blended. With overmixing the doughnuts are tougher and more compact. Longer mixing gives a smoother, softer crust. If the temperature of the ingredients is high the mixing should be shortened.

Kind of flour used. When other conditions are standardized the hard-wheat or strong flours show less fat absorption, the soft-wheat flours more fat absorption. Longer mixing is necessary with soft-wheat than with hard-wheat flours.

The amount of flour. As the amount of flour in the recipe is increased the amount of fat absorbed by the doughnuts is decreased. This is shown in Table 41.

The amount of sugar, fat, and egg. When the sugar and/or fat in the formula is increased, the fat absorption is increased, results similar to those of McKee being obtained. A large amount of sugar gives a soft, runny dough. If the dough is stirred an unusually long time, 200 or more strokes, the fat absorption is decreased. Increasing the fat increases the tenderness of the doughnuts. Increasing the egg gives a softer dough that tends to absorb more fat. On the other hand coagulation of the increased

TABLE 41

EFFECT OF AMOUNT OF FLOUR IN THE RECIPE UPON FAT ABSORPTION IN DOUGHNUTS (*Average 13 tests*)

Experiment 63A. Amount flour, cups	Number of strokes used for mixing	Weight of uncooked doughnuts, grams	Weight of cooked doughnuts, grams	Fat absorption	
				Grams	%
4¾	80	142.6	192.3	72.5	37.4
5	80	140.6	182.4	60.9	33.6
5¼	80	143.2	182.5	59.0	32.5
5½	80	149.0	182.8	51.3	28.2

egg protein tends to decrease fat absorption. The final result is the sum of these two antagonistic effects and the effect of other factors.

The cooking temperature and the length of time of cooking. It has been stated that cooking for 3 minutes at 170°, 185°, and 200°C gave no significant differences in fat absorption. Class results also show that time of cooking and variation in technic of mixing and handling cause greater variation in fat absorption than variation in temperature of 150–200°C. At 150°C the doughnuts are not browned sufficiently to look appetizing even with 4 minutes' cooking time, whereas even 2 minutes at 200°C gives too brown a product. It seems that doughnuts are often overcooked, or cooked at too high a temperature to give the most palatable product. Note the scores in Table 39. Those cooked for 3 minutes at 170°C were lighter in color than is ordinarily considered desirable. It was interesting that the unofficial scorers preferred the light-colored doughnuts. It was customary to sell the extra doughnuts for a penny each. Some girls became regular customers. As long as there was a choice they would select the very light-colored ones and often asked if light-colored ones would be available in a short time.

The amount of fat absorbed by fried foods. The chief factors governing the amount of fat which will be absorbed by a food during frying are (*a*) the time of cooking, (*b*) the total surface area of the food, (*c*) variation in smoking temperature of the fat used, and (*d*) the composition and nature of the food.

In general, the longer a food is cooked the greater the fat absorption. There will be some exceptions to this. For instance, with some foods cooked at high temperatures, coagulated material or a hardened crust may prevent greater fat absorption with longer cooking. Other foods may lose fat during cooking. Examples would be breaded pork chops and fat chicken. Temperature of the cooking fat affects fat absorption indirectly. At low temperatures the tendency is to cook the food longer to obtain the desired browning of the food. The other factors have been considered.

The Shortening Power of Fats and Oils

The fat that covers the greatest surface area of the flour particles in a particular baked product may be said to have the greatest shortening power. Many factors affect the surface area covered by a fat. Among these are: (*a*) the nature of the fat, (*b*) its concentration, (*c*) the temperature, (*d*) the other ingredients and their concentration, and (*e*) the manipulation and extent of mixing.

The nature of the fat. The theory for the shortening of fats and oils has been developed from the work of Langmuir, Harkins, and their coworkers, upon cohesion, adhesion, interfacial tension, and molecular attraction between water and organic liquids. Polar groups or polar molecules are strongly attracted to each other. Water is polar. Some molecules like fats, proteins, and starch contain polar groups (the groups containing oxygen, double bonds, nitrogen, sulfur, and phosphorus). Fats also contain non-polar groups (the hydrocarbon chains). Langmuir (45) found that when a small quantity of oil is placed upon a large clean surface of water it spreads rapidly until a definite area is covered, then shows little tendency to spread further. The cause of the spreading is the attraction of the polar groups of the fat for water. If the whole molecule were attracted by water there would be solubility of the oil in water. Harkins and coworkers (29, 30) have shown that more work is required to separate the oil from the water than when the polar groups are absent.

Langmuir (45) measured the length of the fatty acids, the fat molecule, and the area of the water covered by them. He found the area covered by the saturated acids, palmitic, stearic, and creotic, to be practically the same, yet the number of carbons in each is 16, 18, and 26, respectively. A fat molecule containing 3 saturated fatty acids covered the same water surface as the 3 fatty acids, *i.e.*, the glycerol portion was held against the water surface with the hydrocarbon chains of the acids in the air. All the unsaturated acids covered much greater areas per molecule than saturated ones. The double bonds were attracted to and held to the surface of the water. However, linolic acid covered the same area as oleic, but linolenic with 3 double bonds covered more surface than oleic and linolic. It has been found in studies with pastry that the fat with the greatest unsaturation has the greatest shortening power. The surface area of the flour covered is increased by orientation of the unsaturated glycerides.

Concentration. Other factors being equal the shortening power is increased as the concentration of the fat is increased. The concentration of the fat can be so great that differences caused by fats of varying nature are obscured.

Temperature. The mobility of a plastic fat and an oil is affected by temperature. At lower temperatures, the plasticity of fats is lessened and the viscosity of melted fats and oils is increased. Hence they spread less readily and the area of flour and other ingredients covered is smaller with the same amount of mixing than at higher temperatures. However, at high temperatures gluten absorbs water and becomes attenuated readily. This could offset the tendency of the more mobile fat to cover a greater surface area of the flour.

The other ingredients and their proportion may modify the shortening power of a fat. When an oil or a melted plastic fat is used in a batter with whole egg or egg yolk the fat may be emulsified as an O/W emulsion. When this happens the fat has less shortening power. Cakes made from the same ingredients by the muffin method are less tender than those made by the conventional method. However, even in O/W emulsions the surface of the fat in contact with the water phase varies with the size of the dispersed oil or melted fat particles and with their concentration. Oil is mobile and more easily emulsified than a plastic fat. Melted fat or an oil is usually used in "pour" batters, *i.e.,* griddle cakes, waffles, and muffins. Microscopic examination shows the fat is largely dispersed as an O/W emulsion.

In pastry and biscuits the fat is blended with the flour so that it coats or is adsorbed by the flour. In addition, they usually contain no egg and the proportion of water used in pastry is small.

Manipulation includes creaming or stirring the fat to soften it. It also includes the thoroughness with which the fat is mixed with the flour, the amount of stirring after the liquid is added, the manner of rolling, and handling. The shortening power of a fat may be changed by varying part or all of these factors, and particularly if the temperature is changed a few degrees. Hornstein et al. (33) found no correlation between the breaking strength of pastries and the constants of the fats. They did find the consistency of the fats was softened by cutting or stirring. They suggest that the shortening power may depend upon either the amount of liquid glycerides present or upon the ratio of liquid to solid glycerides.

Pastry

Davis (18) devised an instrument, called a shortometer, for determining the force for breaking and crushing products made into wafers such as crackers, cookies, and pastry. By the Bailey (2) shortometer only the breaking force or strength is determined.

Platt and Fleming (66), by using fat dyed red with Sudan III and examining the baked products microscopically, found the fat to be in thin layers (if examined dry) between the starch granules in cookies. These layers of fat varied in thickness in different sections of the dough. They suggest that viscosity, surface tension of oil, the melting point of the fat, and orientation of the molecule through the double bond of the fatty acid chains of the glycerides have either minor or major effect upon shortening power of fats and oils.

Noble, McLaughlin, and Halliday (63) investigated several factors influencing the apparent shortening value of a fat, using a modified shortbread (sugar added to a pastry formula). They found that creaming the fat and sugar to a maximum volume produced wafers with smaller breaking strength, as determined by a Bailey shortometer, than creaming the same fat to a minimum volume. Also, after adding the flour and liquid to the creamed mass, thorough mixing so that no spots of creamed fat and sugar showed produced markedly more tender wafers than incomplete mixing. If no flour was sprinkled on the board for rolling, wafers markedly more tender resulted than when the minimum amount of flour to prevent sticking was used. Beating the extra flour into the dough gave a more tender product than using it in rolling but a less tender one than omitting it entirely.

Fisher (9, 24) found lard to have the greatest shortening power of the plastic fats tested in pastry. Using 41 and 44% of fat (based on weight of the flour), she found that the shortening value of five lards, two hydrogenated cottonseed oils, one hydrogenated lard, an animal stearin, and one all-vegetable oil compound as determined by breaking strength with the Bailey shortometer approximately paralleled their congealing points, those fats with the lowest congealing point having the greatest shortening power.

Denton and Lowe (20) found that in general the fats and the oils having the highest percentage of unsaturated glycerides gave the shortest pastries. They found an exception in butter, which gave less shortening power than coconut oil, although moisture-free butter, with only the butter fat used, drained free of curd, produced a very tender pastry.

From data, Table 42, it can be seen that the order for different fats in the table varies in some cases according to whether the crushing or the breaking average is taken. Therefore, the results should be taken in groups rather than individual experiments. The oils, corn, cottonseed, and chicken, gave the most tender pastries. The pastries next in order were obtained with second-grade lard, bulk lard, or when a temporary emulsion was made by shaking the oil and the water and then adding this emulsion quickly to the flour.

Lowe, Nelson, and Buchanan (52) and Bernds (4), holding the temperature of the room and the ingredients between 24° and 26°C, found that the temperature of the dough, 25.5–29°C, was always higher than the initial temperature of the ingredients. The three possible sources for this heat are (*a*) the heat of adsorption, (*b*) heat from mechanical friction in mixing, and (*c*) heat from the hand in handling. However, since the hand was used only to form the dough into a mass (10 kneads), and because the dough in some cases was large in quantity, this source probably contributed but little heat. Likewise, because the fat in most instances was mixed with the flour for only 3 minutes and 30 seconds longer after adding the water, the friction did not produce enough heat to cause the total increase in temperature. Hence, most of the increase in temperature must have come from the heat of adsorption of fat and of water by the flour.

TABLE 42 *

Breaking and Crushing Strength of Different Pastries Made under Standardized Conditions. (Each Figure an Average of 48 Tests.) Temperature of Ingredients When Mixed 80°F. (*Denton and Lowe*)

Kind of fat	Melting point, °C	Grams to break	Grams to crush
Puff pastry shortening	61.0	612	1380
Nutmargarine	28.4	644	1096
Puff pastry shortening (moisture-free)		592	1000
Butter, sample I	34.7	530	902
Butter, sample II		525	802
Petrolatum		402	680
Mineral oil, purified		418	635
Nutmargarine (moisture-free)		340	554
Coconut oil		333	588
Commercial coconut fat	19.5	334	537
Lard, all leaf, sample II †	44.6	350	532
Lard, all leaf, sample I		344	477
Lard, largely leaf, sample I	40.6	327	487
Lard, largely leaf, sample III		276	527
Hydrogenated cottonseed oil		317	506
Lard, bulk	45.4	316	466
Cottonseed oil, emulsion made of oil and water		266	528
Lard, second grade	41.4	261	398
Butter, moisture-free, curd removed		268	387
Cottonseed oil		249	399
Corn oil		240	399
Chicken oil or fat		233	375

* Published by courtesy of Dr. Louise Stanley, Chief, Bureau of Home Economics. Experimental work on pastry done at the Bureau of Home Economics, Washington, D. C.

† Average of 96 tests.

Manipulative technics. Certain technics and practices (4) which were found to affect the breaking strength of the pastries would need to be controlled in experiments to determine the comparative shortening power of different fats.

Mixing fat and flour. Unless otherwise stated the figures, p. 540, are averages of 10 mixes, 100 pastries. The extent to which the fat was mixed with the flour, up to the point of optimum mixing, decreased the breaking strength. This optimum time of mixing was obtained in a shorter time with the softer fat (lard) than with the harder fat (hydrogenated lard).

Baking temperatures at 15° intervals from 185° to 245°C gave no significant differences in breaking strengths, though the pastries baked at the highest temperatures were judged more palatable.

Time fat mixed with flour, minutes	2.5	3	3.5
Prime steam-rendered lard, ounces	8.44	7.88	7.93
Hydrogenated lard, ounces	11.15	11.01	10.04

The length of mixing after the water is added also affects the breaking strength of the resulting pastries. The extent of this increased toughness varies somewhat with the flour, its protein content, and its quality.

Time water mixed with fat-flour, seconds	15	30	45
Prime-steam rendered lard, ounces	7.34	8.68	9.10
Hydrogenated lard, ounces	9.01	10.77	12.21

Dough age. The dough rolled immediately after mixing felt soft and tender and was rather easily broken, whereas the dough which stood varying lengths of time was firmer, more elastic, and held together. Pastry from dough rolled immediately had the least breaking strength.

Time after mixing before rolled	Immediately	30 min	2 hr	24 hr
Prime-steam rendered lard, ounces	8.10	9.77	11.12	10.54

Pastry age. The "aging" of the pastry after baking and before testing, up to 2 or 3 hours, increased the breaking strength. However, probably because of staling, standing overnight resulted in decreased breaking strength and loss of crispness. With the rancid hydrogenated lard, the net effect of the rancidity was a slight decrease in the shortening power over that of the fresh hydrogenated lard.

Age of pastry before testing	30 min	1 hr	2 hr	3 hr	24 hr
Prime-steam rendered lard, ounces	8.34	8.38	8.60	8.56	8.26
Hydrogenated lard, ounces	10.32	11.79	11.92	12.60	11.34
Rancid hydrogenated lard, ounces	9.96	11.80	11.93	11.26	10.82

Day-to-day variations. Humidity, atmospheric pressure, and slight unconscious differences in the operator's technic (52) cause significant variations in breaking strength of batches mixed on different days. In testing, to minimize these influences one mix or a multiple number of mixes of each fat should be tested each day.

Texture and temperature of the fat. The texture (52) of the lards, whether smooth or grainy, if from the same source, produces no significant differences in breaking strength. Pastries (4) made from lard at room temperature (24–26°C, average dough temperature 27.4°C) had the least breaking strength, 9.25 ounces, and were probably the least flaky; those from fat at refrigerator temperature (5°C, dough temperature 25°C) were intermediate, with breaking strength of 10.17 ounces; those made with melted fat (60°C, temperature of dough 30.5°C) had the highest breaking strength, 11.42 ounces. The fat at the lowest temperature would be least thoroughly mixed with the flour, whereas the warmest fat elevated the temperature of the flour and dough so that hydration of the flour occurred more rapidly. That variable results might be obtained because of these variables is shown by three short studies (71). The results check those of Bernds, except that in one study the fat from refrigerator produced the tenderest pastry, that at room temperature pastry of intermediate breaking strength.

Chemical and physical constants of the fats. In general, the breaking strength of pastry (52) is related to the iodine value of the fat from which it is made, those fats with higher iodine values, hence the most unsaturated, producing the tenderest pastry. However, because other factors also affect the breaking strength, the degree of unsaturation cannot be taken as the sole criterion of shortening power of the fat.

It is difficult to relate the shortening power of fats to their chemical and physical constants, because these constants vary so widely in different fats. Although fats can be lined up with iodine values in stepwise increments, the melting and congealing points, the smoking point, the peroxide value, and the free fatty acid contents will not vary in a stepwise order. Stepwise variations of these constants can be obtained by blending two fats in different proportions. The results of such blending are shown in Table 43. The means of breaking strengths show the same gradations as the constants.

TABLE 43

Means of Breaking Strength of Pastries Made from Two Lards Blended in Different Proportions (*Bernds*)

Type of lard	Iodine No. (Wijs)	Congealing point, °C	Melting point (polarized light), °C	Peroxide value	Free fatty acids as oleic %	Smoking point, °C	Refractive index at	Means of breaking strength (180 pastries per fat), oz
100% leaf	59.82	29.82	48.9	0.25	0.319	180	1.4586	9.45
75L–25B	60.02	28.95	48.7	0.25	0.284	186	1.4586	9.24
50L–50B	63.38	27.85	46.7	0.50	0.248	188	1.4589	7.93
25L–75B	63.40	26.90	44.8	0.75	0.248	187	1.4595	7.75
100% back	67.52	26.25	42.2	0.75	0.213	191	1.4597	7.14

The substitution (4) of 1, 2.5, 5, and 10% of the lard by the same weight of oleic acid produced pastries with breaking strengths which decreased as the amount of oleic acid increased.

Tenderness of pastry. Some factors affecting the tenderness of pastry have been considered. In addition, increasing the fat results in a more tender pastry. Increasing the water in a given recipe decreases the tenderness of pastry. If both fat and water are increased, the result depends upon the proportion of each used; but unless the increase in fat is very small, the resulting pastry is more tender, the fat having a greater effect than the water. The gluten of pastry flour cannot be developed to the extent that gluten of bread flour can; thus pastry flour gives a more tender pastry than bread flour if the conditions under which the pastries are made are standardized. Excess handling of the dough, *i.e.,* kneading and rerolling, increases its toughness.

Flakiness. Flakiness is considered a desirable quality in pastry. Flakiness depends upon the flour being in layers with greater and lesser concentrations of fat in these layers. Water presumably is imbibed more readily by the portion of the flour not coated so thoroughly with the fat. These layers are separated by the steam and probably to a lesser extent by air in baking. The proportion of fat as well as its consistency affect the flakiness. The fat must be sufficient to coat the flour to a certain extent. A harder fat will not spread as readily as a soft fat and will have flour particles adhering to it. Since water forms the steam, its proportion in relation to the amount of flour and fat, as well as the development of gluten, is important.

The technic of mixing and handling the dough affects flakiness. Peterson (65) has suggested methods of mixing for obtaining flaky, short flaky, and mealy pastry. For a flaky pastry the fat is cut or mixed into the flour with little lumps of fat left throughout the mixture. For a short flaky crust, the flour is mixed thoroughly with half the shortening. The rest of the shortening is added and mixed to leave small lumps of fat. For the mealy pastry it is necessary to mix the fat and flour thoroughly. The fat is mixed well with half the flour. The rest of the flour is added and blended well. In general, the type of pastry designated is obtained, but much depends upon the technic in adding the water and in rolling. Sometimes all three methods yield equally flaky pastry. Extended mixing of the fat with flour tends to give a mealy, less flaky pastry. Oil or melted fats also tend to give mealy pastry, although very flaky pastry can be obtained with oil. Flaky pastry from oil requires more force for breaking than the mealy type with oil.

Rerolling and folding the pastry increases flakiness decidedly, but also increases the toughness. Sometimes small pieces of fat are rolled between the layers of dough to prevent the increased toughness.

Hard-wheat all-purpose flour tends to give a flaky, soft-wheat flours a more mealy pastry. This with the fact that rerolling increases the flakiness suggests that the attenuation of gluten to a slight extent may aid in holding the steam, thus forcing the layers of dough apart. A study just completed in the author's laboratory, in which seven plastic fats were used, indicates that, when temperature of the ingredients and method of mixing are carefully controlled, little variation in flakiness occurs. Flakiness was determined by measuring the height of the pastry, flattening the layers, and again determining the height of the pastry.

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Experiment 62.

Household tests for determining the temperature of fats.

Find the temperature of a fat when a cube of dry bread browns in 60 seconds; in 40 seconds; in 20 seconds.

Make the first test when the fat is at 170°C (340°F). Which temperature is said to be used for cooking raw foods? For browning cooked foods?

Doughnuts

Experiment 63.

To determine the factors which influence the tenderness, the texture, and the amount of fat absorbed in doughnuts.

Recipe:

Flour	5¼ cups	588 grams or use the amount found best under A
Baking powder	2 tablespoons	21 grams
Salt	1 teaspoon	4 grams
Sugar	1 cup	200 grams
Fat	2 tablespoons	25 grams
Eggs	2	96 grams
Milk	1 cup	244 grams
Nutmeg	⅛ teaspoon	
Cinnamon	⅛ teaspoon	

It is more convenient for five or six girls to work in groups for the doughnut experiments. It will take two girls to fry the doughnuts; one to watch the temperature, one to time, to put the doughnuts in, turn, and take them out of the fat. Or a third girl may time the cooking. One girl should do all the mixing, doing it in the same way each time and with the number of strokes designated under each experiment. Another girl should do all the rolling and cutting, handling each batch in the same way and trying not to stretch or pull the cut dough out of shape. Other girls may weigh the materials. The eggs should be beaten together for all the experiments to be done by the group in one period. It is best not to use the results of the first mixing for comparisons but to use them for obtaining technic in handling the dough in mixing, cutting, and cooking.

Directions for mixing.

Remove the flour for rolling before the baking powder is added to it. Sift the remaining flour and baking powder together twice. Combine the thoroughly beaten eggs, sugar, salt, and softened or melted fat, mixing until very light and fluffy. Use the same kind and size of bowl for mixing the materials for each experiment. Add the milk and flour to the other ingredients, and mix the designated amount.

Roll the dough between boards ¼ or ⅜ inch in thickness, tacked to a bread board, so that all the doughnuts will be the same thickness. Each group should use cutters that have the same diameter. If the dough is divided into 2 parts and each half rolled in part of the flour and shaped into a long roll before placing between the boards it facilitates ease of handling. There should be 3 doughnuts from each part of the dough and 6 for each experiment.

In cooking, the doughnuts should be turned when half of the time allowed for cooking is gone. When the time is up, lift each doughnut quickly from the fat onto a skewer held over the kettle so that the fat will drain back into the kettle. The doughnuts should be turned and taken out in the same order that they are put into the fat.

Weigh the kettle of fat before and after cooking the doughnuts for each experiment. The loss of weight of kettle of fat is the amount of fat absorbed by the doughnuts. Weigh the doughnuts before and after cooking if the percentage of fat absorbed is to be calculated. The percentage of fat in the cooked doughnuts may be determined by analysis, but this requires too long a time for class results. The percentage of fat absorbed may be based on the weight of the cooked doughnuts or on the weight of the uncooked doughnuts. Denton has suggested that the former is preferable, and this method has been used in calculating the results given in the tables.

A. To determine the best proportion of flour to use.

The proportion of flour to produce a tender doughnut of good texture varies with different brands and kinds of flour. Therefore, it will be necessary to determine the best proportion for the kind and brand that you use; this proportion is to be used in the following experiments. With some flours it will be necessary to start with 5¾ cups or 6 cups of flour instead of 5½ cups. The dough should be soft and light but not too sticky. If desired, two series of experiments may be run, using bread flour in one and soft-wheat flour in the other.

Prepare ¼ of the recipe, reserving 1 tablespoon of flour for the board. Mix the dough 80 strokes with a wooden spoon. Follow directions for rolling and cutting. Cook the 6 doughnuts for 3 minutes at 175–180°C (345–355°F).

1. Use 5½ cups of flour (616 grams) for the full recipe.
2. Use 5¼ cups of flour (588 grams) for the full recipe.
3. Use 5 cups of flour (560 grams) for the full recipe.
4. Use 4¾ cups of flour (532 grams) for the full recipe.

B. To determine the effect of extent of mixing upon tenderness, texture, and fat absorption of doughnuts.

1. Prepare the full recipe, reserving 4 tablespoons of flour for rolling. Use the proportion of flour found best under A. Mix a total of 40 strokes with a wooden spoon. Observe and record any changes in the dough during mixing. Remove approximately ¼ of the dough (about 280 grams). Follow directions for rolling. Cook the 6 doughnuts for 3 minutes at 175–180°C. Use the remaining dough in the following experiments.

2. Mix the remaining dough from B1 a total of 60 strokes, and remove approximately 280 grams. Proceed as in B1.

3. Mix the remaining dough from B2 a total of 80 strokes. Remove approximately 280 grams. Proceed as in B1.

4. Mix the remaining dough from B3 a total of 100 strokes. Proceed as in B1.

C. Temperature and time of cooking.

Prepare ¼ of the recipe. Use the proportion of flour found best under A, and mix with the number of strokes found best under B.

1. Cook 2 minutes at 155–160°C (310–320°F).
2. Repeat C1, but cook 3 minutes.
3. Repeat C1, but cook 4 minutes.
4. Repeat C1, but cook 2 minutes at 175–180°C (345–355°F).
5. Repeat C1, but cook 3 minutes at 175–180°C.
6. Repeat C1, but cook 4 minutes at 175–180°C.
7. Repeat C1, but cook 2 minutes at 195–200°C (380–390°F).
8. Repeat C1, but cook 3 minutes at 195–200°C.
9. Repeat C1, but cook 4 minutes at 195–200°C.

D. To determine the effect upon fat absorption of letting the dough stand a short time before cooking.

1. Prepare all the recipe. Reserve 4 tablespoons of flour for rolling. Use the proportion of flour found best under A and the number of strokes for mixing found best under B. Use the time and temperature of cooking found best under C. Use approximately ¼ of the dough, and cook the doughnuts as soon as possible after mixing and rolling.

2. Use approximately ¼ of the dough, and let the doughnuts stand ½ hour or longer after rolling and cutting before they are cooked. Use the remaining dough for the following experiments.

3. Let approximately ¼ of the dough from D1 stand for ½ hour or longer; then roll, cut, and cook the doughnuts.

4. Let ¼ of the dough from D1 stand ½ hour or longer. After the dough has stood, mix with 10 additional strokes before rolling.

If desired, 1¼ times the recipe may be mixed and one part of the dough chilled ½ hour or longer before rolling.

E. To determine the effect upon the texture and fat absorption of increasing the proportion of sugar.

1. Prepare the full recipe, using the proportion of flour found best under A. Reserve 4 tablespoons of flour for rolling. Increase the sugar to 1½ cups (300 grams). Mix 140 strokes with a wooden spoon, and remove approximately ¼ of the dough (about 300 grams). Roll according to directions. Cook 6 doughnuts at 175–180°C for 3 minutes or at the temperature and time found desirable under C.

2. Mix the remaining dough from E1 a total of 160 strokes, and remove approximately 300 grams. Follow directions under E1.

3. Mix the remaining dough from E2 a total of 180 strokes, and remove approximately 300 grams. Follow directions under E1.

4. Mix the remaining dough from E3 a total of 200 strokes. Follow directions under E1.

F. To determine the effect upon the texture and fat absorption of increasing the fat in the recipe.

1. Increase the fat in the recipe to 4 tablespoons. Prepare ½ the recipe, reserving 2 tablespoons of flour for rolling. Use the proportion of flour found best under A. Mix 80 strokes with a wooden spoon, and remove approximately ½ of the dough (about 280 grams). Follow directions under E1.

2. Mix the remaining dough from F1 a total of 100 strokes. Follow directions under E1.

G. To determine the effect upon the texture and the fat absorption of increasing the egg in the recipe.

Increase the eggs in the recipe to 3. Repeat directions for F.

H. To determine the effect upon the texture and fat absorption of adding the flour and milk in portions.

Prepare ¼ of the recipe. Use the proportion of flour found best under A and the number of strokes found best for mixing under B. Follow directions for cooking used for B. Compare with doughnuts from B. Add approximately ⅓ of the flour and ⅓ of the milk to the egg-sugar mixture. Stir approximately ⅓ of the total number of strokes to be used for mixing. Add the second ⅓ of the milk and flour, stirring ⅓ of the total number of strokes. Add the remainder of the flour and milk, and stir the number of strokes needed to make the total desired.

If the flour and milk are to be stirred a total of 80 strokes, the first ⅓ may be stirred 25 strokes, the second ⅓ 25 strokes, and the remainder of the flour 30 strokes to make a total of 80 strokes.

What is the effect of increased mixing of the dough upon fat absorption in doughnuts? Does the dough become more or less sticky with longer mixing? Which amount of mixing gives the best flavor and the best texture? The least fat absorption? What is the effect of length of time of cooking upon fat absorption of doughnuts? The effect of temperature of cooking? Compare the dough that has stood with the dough that did not stand, in respect to the ease of rolling and the consistency. Does chilling increase the ease of rolling? What is the effect upon the texture and the fat absorption of standing before cooking?

What is the effect of increasing the sugar in the recipe upon fat absorption? Upon texture? Does increase of sugar in the recipe require longer mixing of the dough? Is there any relation between the texture of the doughnuts with increased sugar and the texture of cakes when the proportion of sugar is increased? What is the effect of increasing the proportion of egg upon the texture of the doughnuts? Upon fat absorption? Of increasing the fat? Adding the flour in portions instead of all at once? Which doughnuts have the best texture? The best flavor?

Write a summary of the factors that affect the fat absorption in frying doughnuts. Compare your results with those published in the literature, and with previous classes.

Suggestions for additional experiments with doughnuts.

1. Vary the method of mixing.
2. Vary the kind of fat used and its temperature when added to the doughnuts.
3. Determine the amount of mixing that is desirable with each type of baking powder.
4. Turn the doughnuts several times during cooking.

Pastry

Experiment 64.

To determine the factors that influence the quality of pastry.

Recipe:

Flour, all-purpose	1 cup	112 grams
Fat	⅓ cup	66 grams
Salt	½ teaspoon	2 grams
Water		

Directions for mixing.

The flour may be either a hard- or soft-wheat all-purpose one. If a soft-wheat flour is used, it is probably preferable to reduce the proportion of fat to ¼ cup (50 grams).

Place the weighed flour and the salt in a bowl, add the fat, and cut into the flour with a fat cutter. The fat may be worked into the flour by rubbing between the tips of the fingers. The fat should be mixed with the flour until the mixture resembles coarse corn meal. The number of strokes required to cut the fat into the flour will vary, the hard, cold fats requiring far more strokes than the softened fats or the oil. A record may be kept of the number of strokes required for comparison of ease of mixing. In mixing the fat with the finger tips, work quickly so as not to melt the fat. Compare your fat and flour mixture with your neighbors' to see if they are about the same consistency. Add the water in such a manner that it is distributed rather evenly over the flour mixture. Cut the water into the fat and flour, or stir with a two-tined fork.

The pastry rolls better if allowed to stand about 5 minutes after mixing. Then work into a ball, using 8 motions of the hand to get the material together. In rolling the pastry some can be rolled without adding flour to the board, but do not use more than 1 teaspoon of flour for each pastry. The pastry may be rolled between boards ⅛ to ³⁄₁₆ inch in thickness, which are tacked to the bread board. Strips of wax paper just wide enough to fit between the cleats may be used for rolling and handling the pastry. One piece of paper is placed between the cleats. The dough to be rolled is placed on this paper and a second sheet of paper is placed over the dough. After rolling, the top paper is removed. The dough is lifted on the lower sheet of paper and is placed on the baking sheet or tin by inverting the paper, pressing lightly, and then removing the paper. If the dough is rolled in long strips, it should be shaped into a long strip before rolling. For the pastries in which the proportion of ingredients is changed until they will not roll easily, the pastry can be partially rolled, then placed in the pan and patted quickly to the same thickness as the rolled pastry. If the pastries are not the same thickness they bake differently and require different lengths of time for baking.

Bake in pans of the same size, shape, and material. Bake at 220–225°C (425–435°F), until a light golden brown.

A. To determine the proportion of water and the amount of mixing to give a desirable pastry with the brand of flour used.

Use the same fat throughout the A series. Mix the full recipe.

1*a*. Use 24 ml of water. Add water as evenly as possible over the surface of the fat-flour mix. Mix 20 strokes with a 3-tined fork (less for a 4-tined and more for a 2-tined fork). Remove ¼ of the mixture, form into an elongated strip and roll.

1*b*. Stir the dough 10 more strokes. Remove ⅓ of the remaining dough, and roll.

1*c*. Stir the dough 10 more strokes. Remove ½ of the remaining dough, and roll.

1*d*. Stir the remaining dough 10 more strokes. Roll.

2*a, b, c, d*. Repeat A1, but use 30 ml or grams of water.

3*a, b, c, d*. Repeat A1, but use 36 ml or grams of water.

4*a, b, c, d*. Repeat A1, but use 42 ml or grams of water.

B. To determine the effect of different kinds of fat in obtaining a desirable pastry. Use the proportion of water found best under A.

1. Use butter as the fat. Divide into 4 portions, stirring 20, 30, 40, and 50 strokes as under A1.
2. Repeat A1, but use an oil.
3. Repeat B1, but use a lard.
4. Repeat B1, but use a hydrogenated shortening.

C. To determine the effect of different proportions of the fat in obtaining a desirable pastry.

Decide on the kind of fat and the proportion of water, or use as many kinds of fat as desired.

1. Increase the fat to 100 grams. Divide dough into 4 parts, stirring 20, 30, 40, and 50 strokes.
2. Repeat C1, but reduce the fat to 50 grams.
3. Repeat C1, using 66 grams of fat for a control.

What is the effect of increased mixing upon the tenderness of pastry? Upon its flakiness? Which amount of mixing results in the best pastry? What is the effect of substituting soft-wheat for hard-wheat flour? Can the fat be reduced when pastry flour is used? Can the pastry-flour pastries be mixed longer than bread-flour ones? Which pastries roll most easily? Which are difficult to handle? Which fat gives the shortest pastry? Which the toughest? Which fat produces the most flaky pastry? Which the least flaky? Which flour produces the flakiest pastry? Which a mealy pastry?

Experiment 65.

To determine the effect of the temperature of ingredients when mixed upon the texture and tenderness of pastry.

1. Use all-purpose flour and lard. Use the proportion of water found best under 64A, and mix with the number of strokes found best under 64A. Use ice water and chilled fat.
2. Prepare twice the quantity used in the other experiments. Repeat 1, but have the water boiling. Add the fat, and stir until the fat is melted. Then add the flour and salt, and mix with the number of strokes found best under 64A. Divide into two portions. Roll and bake one part. Use the other portion for 3.
3. Chill the dough remaining from 2 before rolling.
4. Repeat 1, but melt the fat before cutting into the flour.

Which gives the flakiest pastry? Is the pastry made with hot water difficult to roll unless chilled?

Experiment 66.

To determine the effect of mixing by different methods and rerolling of pastry.

1. Repeat Experiment 65, 1, but prepare twice the quantity used in the other tests. Roll and bake half the dough. Use the other portion for 2.
2. Reroll the dough remaining from 1 four or five times, and bake. Compare with 1 for flakiness and tenderness.

3. Use all-purpose flour and lard. Use the proportion of water found best under 64A. Put all the ingredients in the mixing bowl together. Then cut with a fat blender or a two-tined fork until the dough is the consistency to roll. Compare with other methods of mixing.

4. Use all-purpose flour and lard. Mix the fat into the flour so that small lumps of fat remain. Use the proportion of water found best under 64A. Add the water, and mix with the number of strokes found best under 64A.

5. Repeat 4, but mix half the fat thoroughly with the flour. Add the rest of the fat and mix so that small lumps of fat remain in the mixture.

6. Repeat 4, but cut the fat thoroughly into half of the flour. Add the remaining flour and mix well.

7. Repeat 4, but decrease the fat in the full recipe to 40 grams. After rolling the dough add 5 grams of fat in small flakes over half the rolled dough. Fold the dough and reroll. Add 5 more grams of fat and reroll.

What is the effect of rolling the dough several times upon the tenderness of the pastry? Its flakiness? Can a good pastry be obtained by combining all the ingredients at one time? Does adding a portion of the fat while rolling increase the flakiness of the pastry? Its tenderness?

Experiment 67.

To determine the best method of preventing juicy fruit from soaking the crust in pies.

Make enough pastry at one time for all the tests. It can be made with the KitchenAid or mixed by hand. After mixing, divide the pastry into 8 parts. Knead each part 5 times. The amount of pastry needed will depend on the size of the pie tin and the thickness of the pastry. For 1-inch deep, 6-inch-diameter tins and using pastry rolled ⅛ or 3/16 inch in thickness, 6 times the recipe in Experiment 64 will yield 2 crusts for 8 pies. Roll the pastry the same thickness for all pies, using cleats (⅛ to 3/16 inch) tacked on a large bread board. Bake at 220–225°C (425–435°F). The temperature may be lowered if necessary for the last part of the baking.

To standardize the amount of juice that goes into each pie the fruit and juice should be weighed separately. The amount of juice and fruit will be determined by the size of the pie pan. For the pan of the size mentioned, the following proportions work well. For each pie use 130 grams drained, sour, water-packed cherries, 60 grams juice, 5 grams of butter, and 30–35 grams of sugar. Water-packed berries may be used instead of cherries, but the amount of sugar may need to be lowered.

1. Use the sweetened fruit mixture for a control.

2. Brush the top of the under crust with melted butter. Then add the sweetened fruit and juice.

3. Brush the top of the under crust with egg white. Add the sweetened fruit and juice.

4. Repeat 3 but partially bake the under crust. Then add the fruit and top crust and bake.

5. For each cup of juice (about 240 grams), use 1 tablespoon of cornstarch (9 grams). Mix the juice and cornstarch. Cook until thickened. Add the cherries, sugar, and butter. Heat to boiling. Place in the lower crust. Add

top crust and start baking as soon as possible. The baking time is shortened when a hot filling is used.

6. Sprinkle the top of the lower crust with flour.

7. Mix the cornstarch or flour with the sugar. Add to the fruit. Use the same proportion of cornstarch used under 5. When flour is substituted for cornstarch, how much should be used? This method works better with fresh fruit than with canned fruit. Why?

8. Repeat 5, but bake the pie at a much lower temperature than that used for the other pies.

Should the proportion of thickening be changed for very sour and for less tart fruit juices? Why?

Experiment 68.

To determine the best methods for preventing a soggy crust with a custard pie.

A. Make enough pastry at one time for all the tests. See Experiment 67. Prepare the custard mix for all the pies at one time. For the 1-inch deep, 6-inch-diameter tins, 180–190 grams of the mix is enough for 1 pie.

Recipe:

Milk	1 cup	244 grams
Egg	1.5	72 grams
Sugar	2 tablespoons	25 grams

1. Roll crust, place in tin. Prick. Partially bake, then add the custard mix. Bake at 175°C (350°F).

2. Repeat 1, but brush the top of the crust with egg white before partially baking.

3. Roll crust, place in pie pan. Add the custard mix that has been heated quickly to 80°C (175°F). Bake at 175°C (350°F).

4. Repeat 3, but use the cold custard mix.

5. Repeat 1, but bake 10 minutes at 210°C (425°F), then transfer to a second oven at 175°C (350°F).

6. Invert the pie tin and place crust on bottom of the pan. Prick, or place a second pan over the top of the crust. Bake at 210°C (425°F). Bake the custard in another pan of the same size at 165–175°C (325–350°F). Place the pan and custard mix in a shallow pan and surround with water for baking. Bake until the custard has thickened. Cool the custard in the pan until the pan can be held comfortably in the hand. Run a knife around the edge of the custard. Tilt the pan, and shake the custard into the baked crust. Be sure the edge of the custard is at edge of the pastry when the shaking is started. If the custard is not partially cooled it will not hold together so well, and if it is too cold it becomes brittle and breaks.

B. The baking temperature.

Repeat portions of Experiment 68A but bake at higher or lower temperatures.

C. The proportion of egg in the custard mix.

The number of eggs per cup of milk used in custard pies varies. Repeat A6, using 1, 1.5, and 2 eggs per cup of milk, and determine which proportion of egg you like best.

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